CALIFORNIA UNDERCURRENT RECONNAISSANCE
BETWEEN
MONTEREY AND SANTA BARBARA

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NAVAL POSTGRADUATE SCHOOL
Monterey, California

THESIS

California Undercurrent Reconnaissance
between
Monterey and Santa Barbara

by

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Thesis Advisor: J. B. Wickham

September 1972

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ABSTRACT

Continuous temperature and salinity profiles were made on nine sections of stations between Monterey and Santa Barbara to locate the California undercurrent. Temperature-salinity relations across all sections indicated the presence of southern water characteristic of the undercurrent. Tongues of high temperature water were found to extend northward implying northward and southward flow both at 200 and 300 meters. The sudden fall of isotherms coupled with a rise in isohalines across sections seven and eight together with the observation of numerous temperature inversions indicated the influx of warm, salty water from the south.

These data suggest that the boundaries of the California undercurrent between Monterey and Santa Barbara extend from five nautical miles to beyond 25 nautical miles offshore below 200 meters during the period of this investigation.

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ACKNOWLEDGEMENTS

The author wishes to express appreciation for the assistance given by his advisor, Professor J. B. Wickham of the Department of Oceanography of the Naval Postgraduate School. Appreciation is also expressed to the officers and men of the USNS BARTLETT. I would like to thank Professor Galt, Jack Mellor, Rick Desgrange, all of the Department of Oceanography of the Naval Postgraduate School, and Dave Bennett, world champion teeter-totter rider, for their assistance in standing watches on the BARTLETT.

I. INTRODUCTION

A. DESCRIPTION OF THE CALIFORNIA CURRENT SYSTEM

The California current is defined by Sverdrup, Johnson and Fleming [1942] as lying between latitudes 48° and 23°N. It is a continuation of the Japanese current after the Japanese current has mixed with subarctic water and has become known as the Aleutian current. The California current flows southward along the California coast with its outer boundary being as far as 700 km from the coast. Emery [1960] estimates the total volume transport of the California current as from a fifth to a tenth of that of the Gulf Stream. High current velocities generally are not encountered.

The seasonal variations of the California current and the effects of the atmosphere on these variations have been discussed by Sverdrup and Fleming [1941], Pavlova [1967], Wooster and Reid [1963], and Reid, Roden and Wyllie [1967]. In particular, there is a northward flowing countercurrent shoreward of the main southward flowing California current. This countercurrent generally exists throughout the year, and can be found, depending on the season, from Pt. Eugenia to Cape Mendocino. In the winter months and in the absence of north-northwest prevailing winds, this current extends to the surface and is known as the Davidson Current north of Pt. Conception. With the onset of the north-northwest winds, upwelling begins along the California coast and the

countercurrent disappears above 200 m. However, below 200 m the countercurrent remains in existence. This northward flowing current, in the absence of the surface countercurrent, has been called the California undercurrent. Wyllie [1966] pointed out that there is also an annual variation in the seasonal characteristics of the California current system.

B. PREVIOUS STUDIES RELATING TO THE CALIFORNIA UNDERCURRENT

Sverdrup and Fleming's [1941] definitions of northern and southern water was based partly on data obtained during a series of cruises from March to July, 1937. They found that a characteristic of southern water was a T-S curve on which salinity was relatively constant as temperature decreased (see Figure 1, curves S.3 and BIII, 31). A T-S curve for northern water showed an increase in salinity with decreasing temperature (Figure 1, curve C131). They have constructed a chart defining percentage southern water for given T-S pairs (Figure 2). Based on this definition they were able to trace southern water as far north as Cape Mendocino. They also found that most southern water close to the continental slope was within the northward flowing current. As might be expected, the percentage of southern water decreases in the direction of flow in the northward flowing current. Sverdrup and Fleming [1941] and Wyllie [1966] showed the existence of northward flowing undercurrents based on dynamic height calculations. Figures 3 and 4 are charts from Wyllie [1966] showing geostrophic flow at

the surface and at 200 meters. The existence of an undercurrent as far north at Pt. Conception is readily apparent. However, Reid, Roden, and Wyllie [1958] have pointed out the doubtful validity of computing currents from the density structure close to shore. Direct measurements using drogues have been made by Reid [1962], Reid and Schwartzlose [1962], and Reid [1963] which have indicated a northward flowing current at 200 meters off Monterey, California and Baja California, and the existence of this countercurrent at the surface in winter months. The existence of an undercurrent can also be inferred from the distribution of properties such as temperature, salinity, and oxygen content within the water type. Wooster and Jones [1970] indicated that a characteristic of the undercurrent was a "bulge" in salinity on a T-S plot (Figure 5). Wooster and Reid [1963] point out that a coastward deepening of isopleths of temperature, salinity, and density is characteristic of a poleward countercurrent. Figures 6 and 7 indicate this feature for isotherms and isohalines as found by Wooster and Jones [1970]. Wooster and Jones [1970], Wickham [in preparation] and Roden [1964], have indicated that temperature inversions may exist in the areas of the California undercurrent due to the overflowing of cool low salinity water over warmer, higher salinity water.

C. STATEMENT OF THE PROBLEM

The existence of the undercurrent can be inferred from the action of isopleths near the coast or from temperature inversions.

inversions. Furthermore, the southern water making up this northward flowing undercurrent can be identified by specific T-S relationships. One thing that should be noted is that most of the data from which these facts were inferred have been taken at stations widely separated both in space and time. The work of Wooster and Jones [1970] off Baja California provided a notable exception. They recommend the use of a profiling device to delineate the northward extent of high salinity water and to locate areas where subsurface salinity measurements could monitor undercurrent variation. Bourke and Wickham [1972] have proposed a study to locate the Davidson and California undercurrent intrusions off the coast of central California, to examine spatial and temporal variations in the currents, to study mass and momentum exchanges involving meso-scale features, to relate the activity off the central California coast to that observed in southern latitudes and to determine models for dynamics of the flow.

One of the initial steps is to collect data along a finely spaced grid of stations in the shelf zone and to examine these data for areas of definite or possible undercurrent intrusion. This initial step is the problem addressed in this thesis.

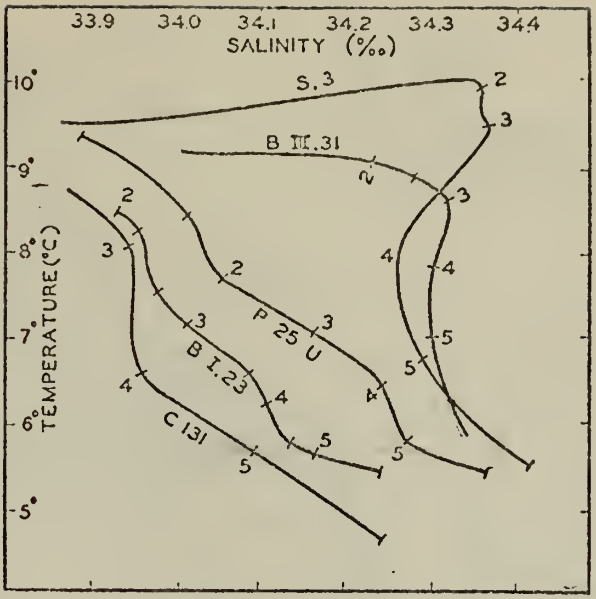

Figure 1. Temperature-salinity curves from selected stations [from Sverdrup and Johnson, 1941].

S3 BIII Southern water

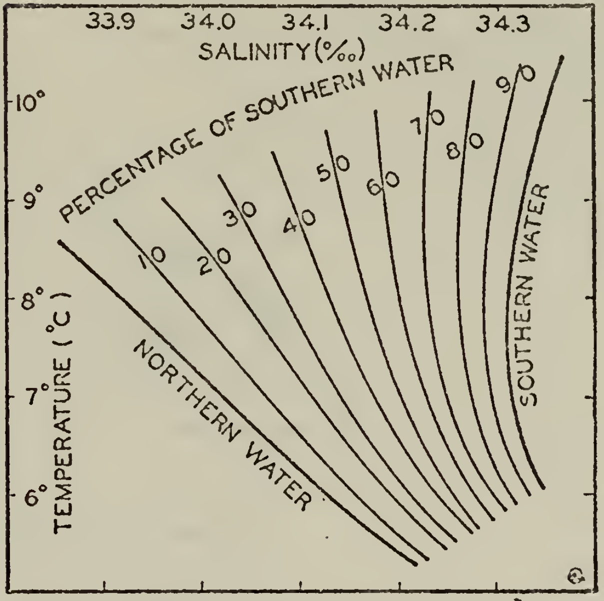

Figure 2. Diagram showing T-S curves defining percentage southern water [from Sverdrup and Johnson, 1941].

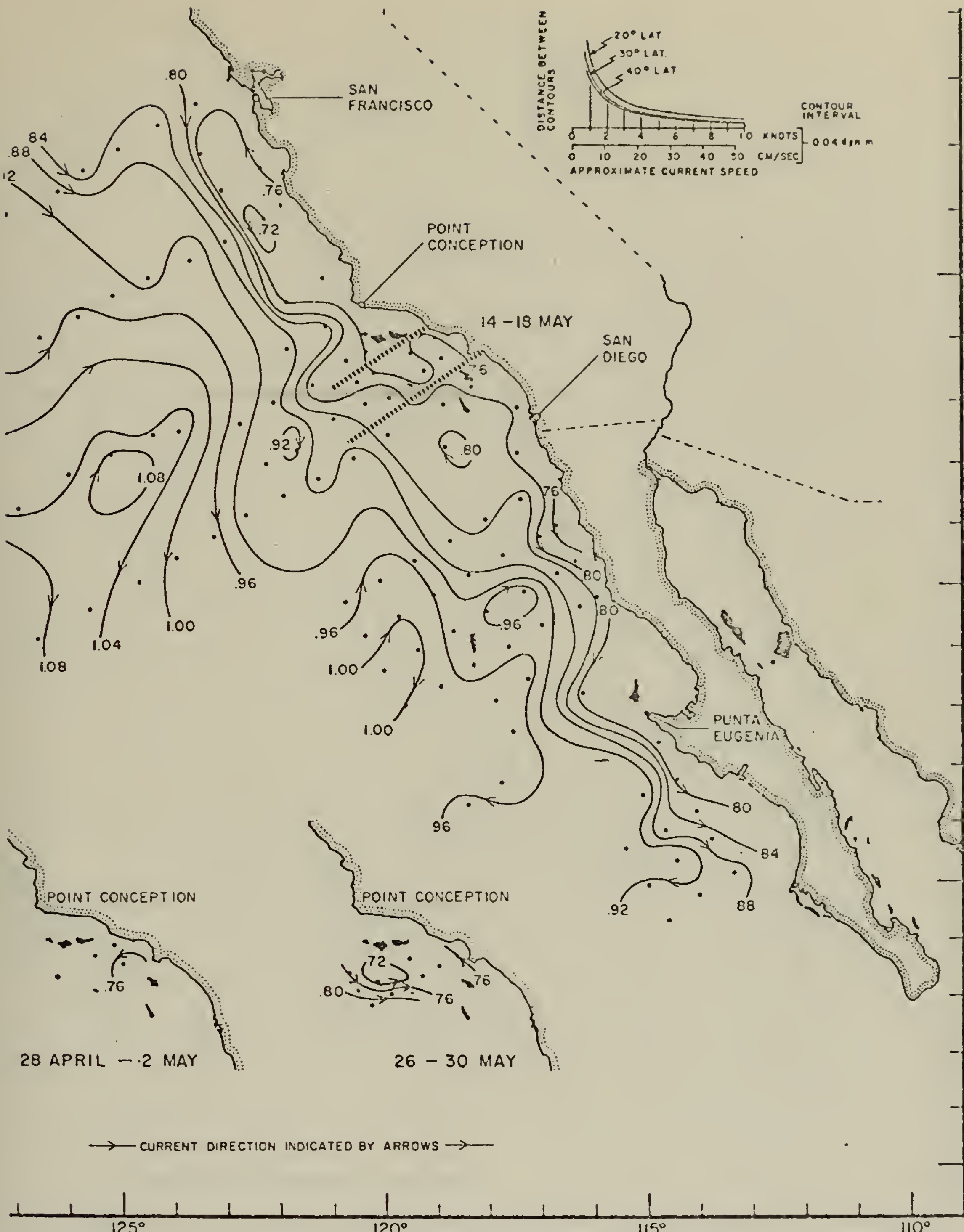

Figure 3. Geostrophic flow of the California current at the surface, 28 April - 30 May 1953 [from Wyllie, 1966].

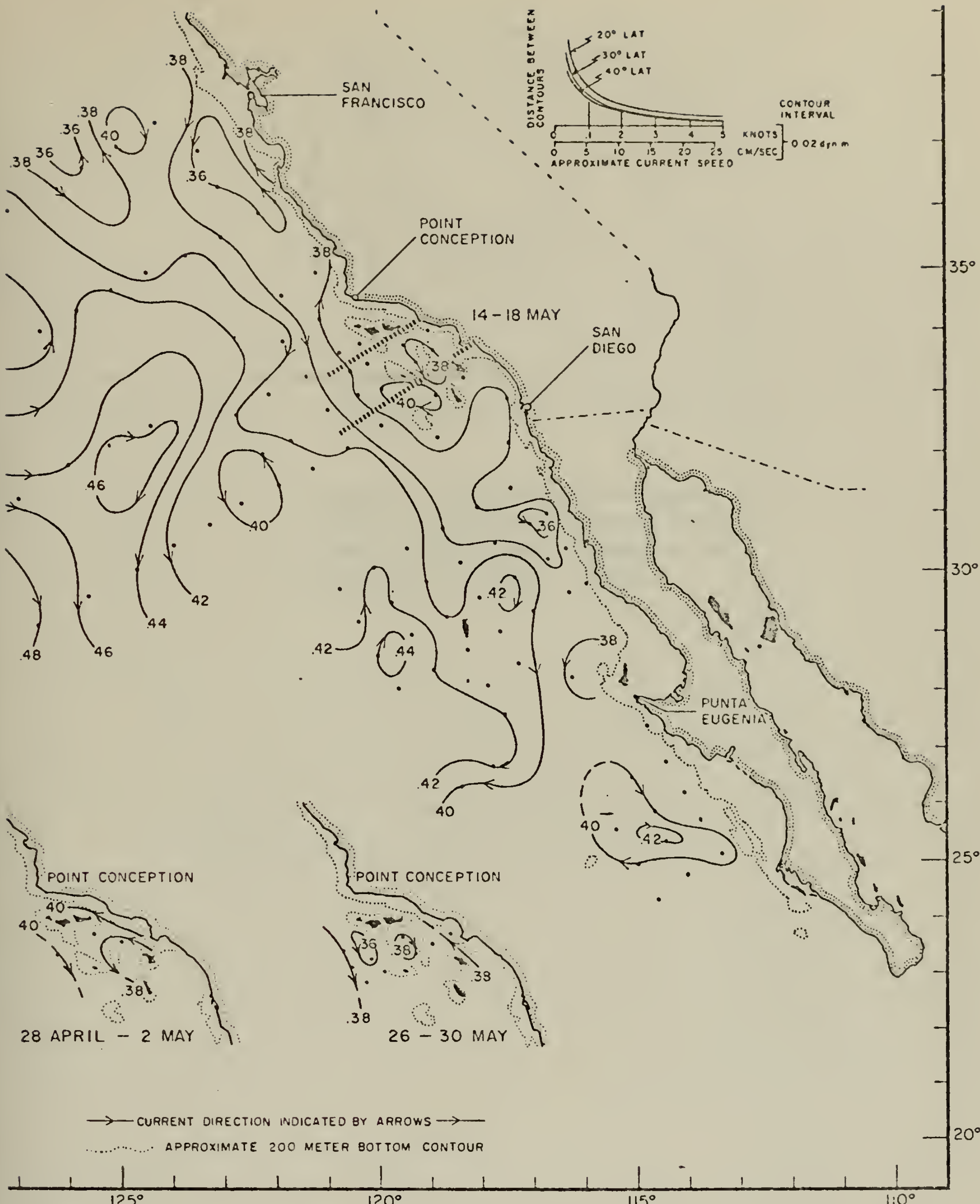

Figure 4. Geostrophic flow of the California current at 200 meters, 28 April - 30 May 1953 [from Wyllie, 1966].

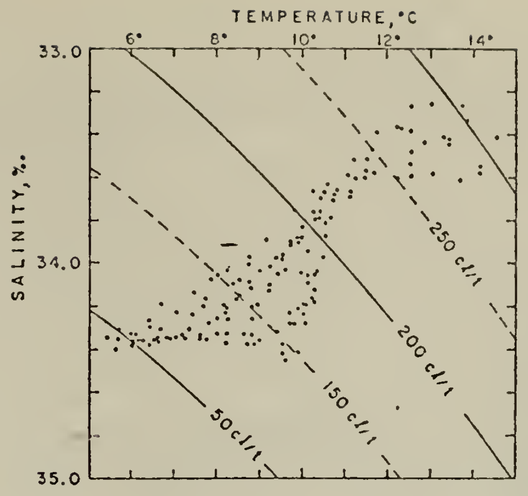

Figure 5. Temperature-salinity relationships for selected stations in California undercurrent [Wooster and Jones, 1970].

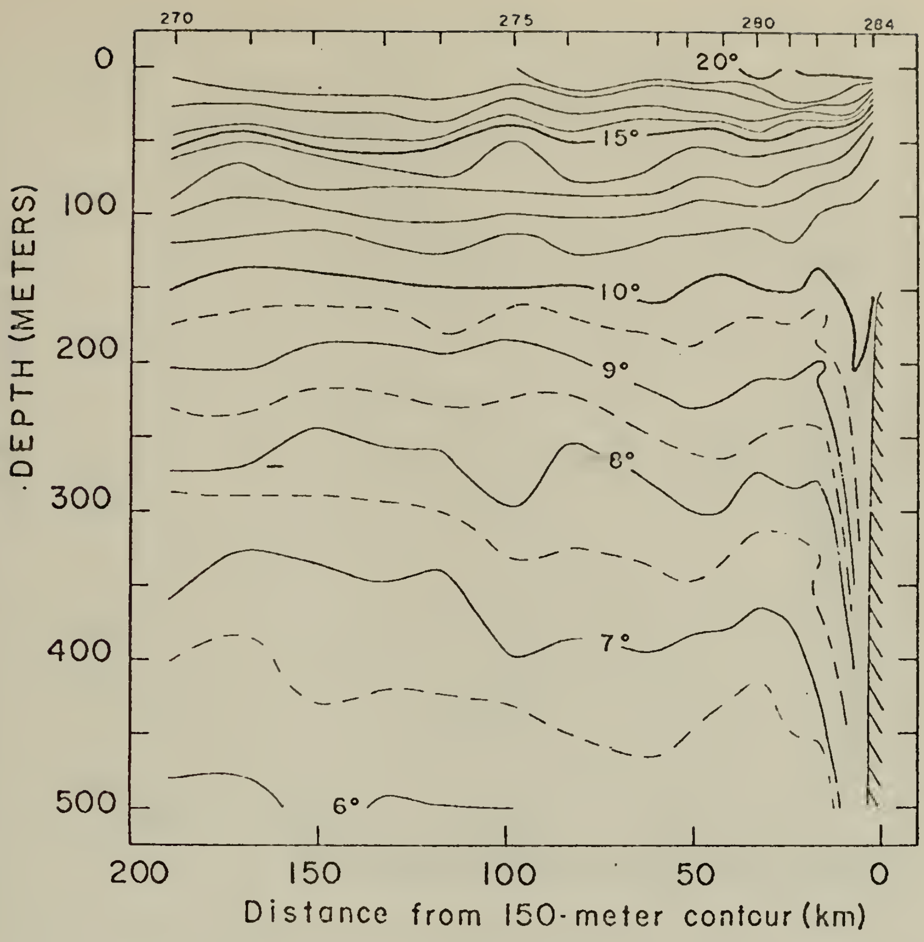

Figure 6. Distribution of temperature on reconnaissance section [from Wooster and Jones, 1970].

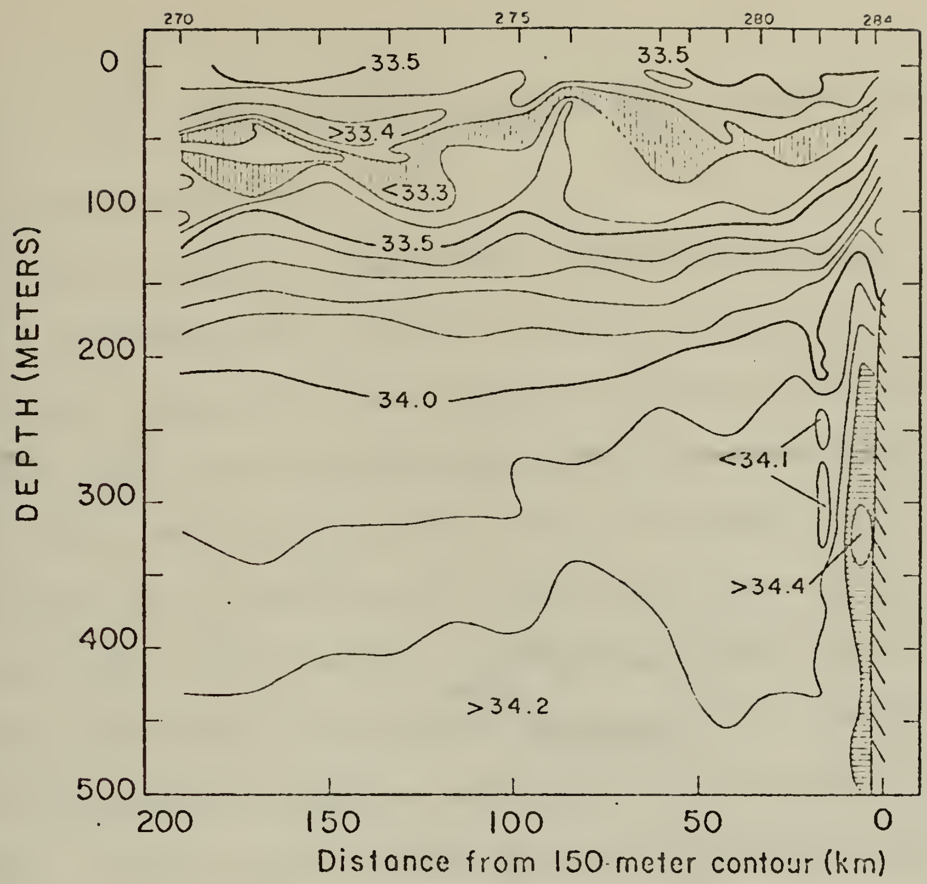

Figure 7. Distribution of salinity on reconnaissance section [from Wooster and Jones, 1970].

x section

plan

II. RECONNAISSANCE CRUISE DATA COLLECTION

A. CRUISE PLANNING

The oceanographic ship USNS BARTLETT was made available for a reconnaissance cruise from 22 May to 27 May 1972. A detailed cruise plan was drawn up calling for some 184 stations along ten sections between Monterey and Santa Barbara. The first two sections were taken as planned, but the original plan had to be modified when experience showed that stations took longer than planned. In order to still cover the entire distance, the station spacing was increased from one to two miles by skipping odd-numbered stations. Sections seven, eight, and nine were replotted and the stations renumbered with station interval equal to two miles. Original station spacing of one mile was chosen so that features as small as one mile could be detected. The first five section positions were chosen to investigate the features both to the north (sections one and two) and south (sections three, four, and five) of Pt. Sur to determine the character of the water moving around Pt. Sur. Sections seven, eight, and nine were positioned so that the character of water in the Santa Barbara channel could be compared with the character of water in the area to the north and west of Pt. Arguello for possible inferences about flow through the channel. Section six was positioned between Pt. Arguello and Pt. Sur for a check on the nature of the flow between these points.

An overview of sections one - nine is shown in Figure 8. Charts of individual sections are shown in Figures 9-14. Positions of the individual stations were found by radar navigation. Table I shows latitude and longitude of individual stations.

B. INSTRUMENTATION

The primary instrument used was the Bisset Berman Model 9040, SV/STD (sound velocity/salinity/temperature/depth). The manufacturer's specifications claim an accuracy of $\pm$.02°C for temperature and $\pm$.03 ppt for salinity. Sound velocity was not measured during the reconnaissance cruise. At 12 stations, a Nansen bottle was placed on the SV/STD cable approximately one meter above the SV/STD (see Table I for station numbers). A water sample was taken at each of the 12 stations and the salinity was determined using a salinometer. The first salinity value determined in this manner was anomalously high for the depth of the sample and when compared to SV/STD data, was not within specifications of the instrument. All 11 subsequent values were within $\pm$.03 ppt of the salinity as read on the SV/STD. It was therefore assumed that the first salinometer reading was in error, and that the accuracy of the salinity read on the SV/STD was sufficient for our purposes. Values of temperature read on the reversing thermometers were all within $\pm$.02°C of the SV/STD values.

The SV/STD Model 9040 consists of an underwater unit and a desk unit. The underwater unit includes precision transducers which sense salinity, temperature, depth, and sound velocity. These transducers produce voltage varying signals which are converted into a multiplexed FM signal which is transmitted through cable to the desk unit. There the signals are demultiplexed and demodulated. The analog voltage varying signals are recorded on a continuous chart recorder. Digital data is available in the form of punched paper tape. Problems encountered in handling these data are discussed in the Appendix.

The size of features detectable by the SV/STD are dependent on the time constants of the sensors and the rate of lowering (or raising) the instrument. A lowering speed of 40-50 meters/minute coupled with a time constant of .35 seconds for the temperature sensor would imply that features as small as two meters could be detected. This is close to the limit of accuracy in reading depth from the chart on the scales used.

Spikes in the salinity trace are known to be caused by the mismatch between the time constant of the conductivity sensor and the platinum resistance thermometer used to correct the conductivity measurements to salinity. Goulet and Culverhouse [1972] have noted spikes with slower decay times than would be expected if the temperature time constant was as specified. They have calculated the temperature time constant to be up to an order of magnitude larger than specified.

An examination of the data taken on this cruise showed that salinity spikes were normally only of the thickness of the pen trace. However, even considering this fact and the additional fact that Goulet and Culverhouse [1972] examined a different model STD, it is apparent that the manufacturer's claim for time constants of the sensors on the SV/STD should be checked experimentally on future cruises.

Although during the up cast of the SV/STD the sensors are being towed through water disturbed by the instrument, up and down traces taken throughout the cruise showed good general agreement. Furthermore, data used for analyses were taken only from down traces.

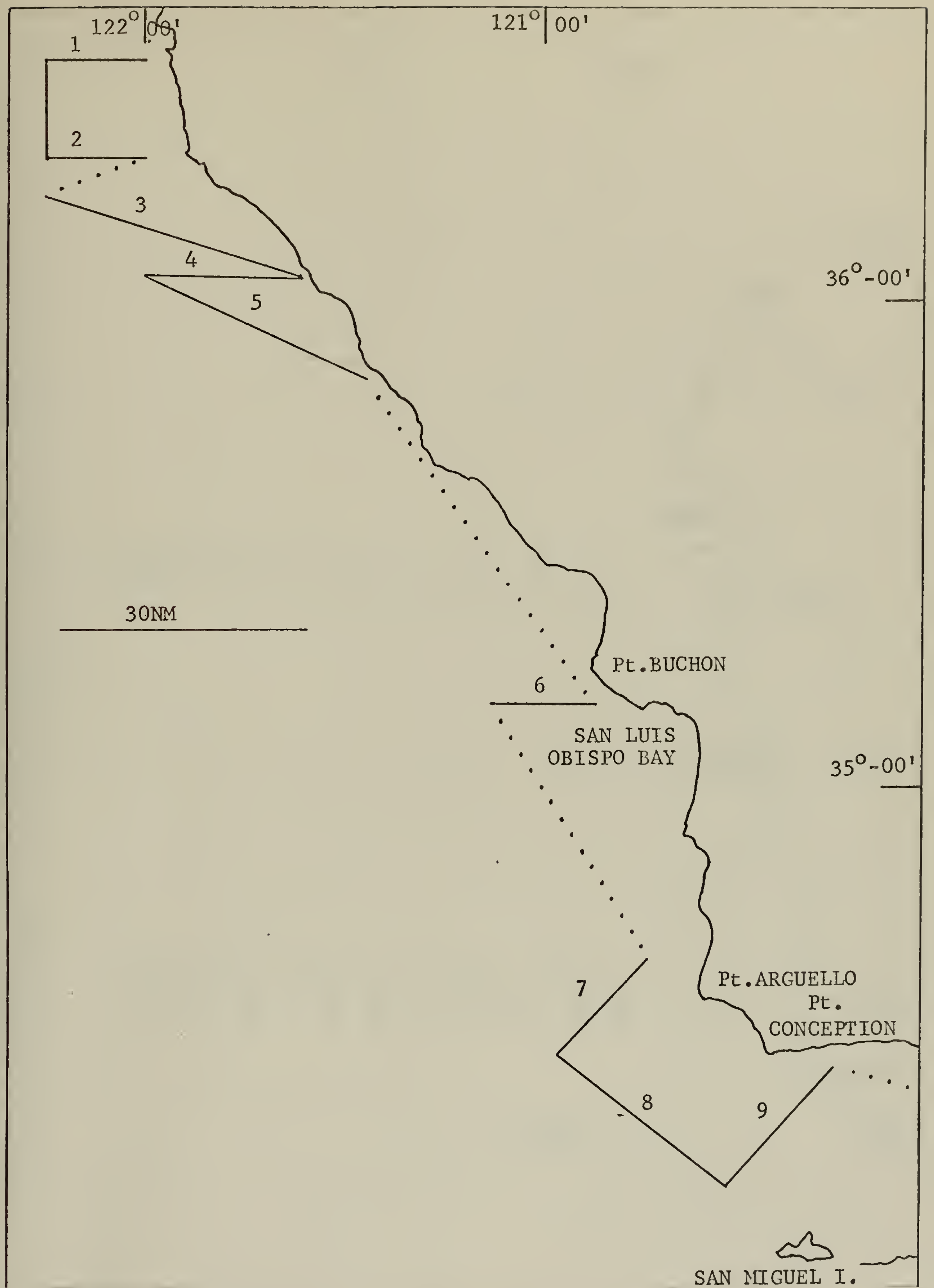

Figure 8. Overview Chart of USNS BARTLETT Reconnaissance Cruise sections.

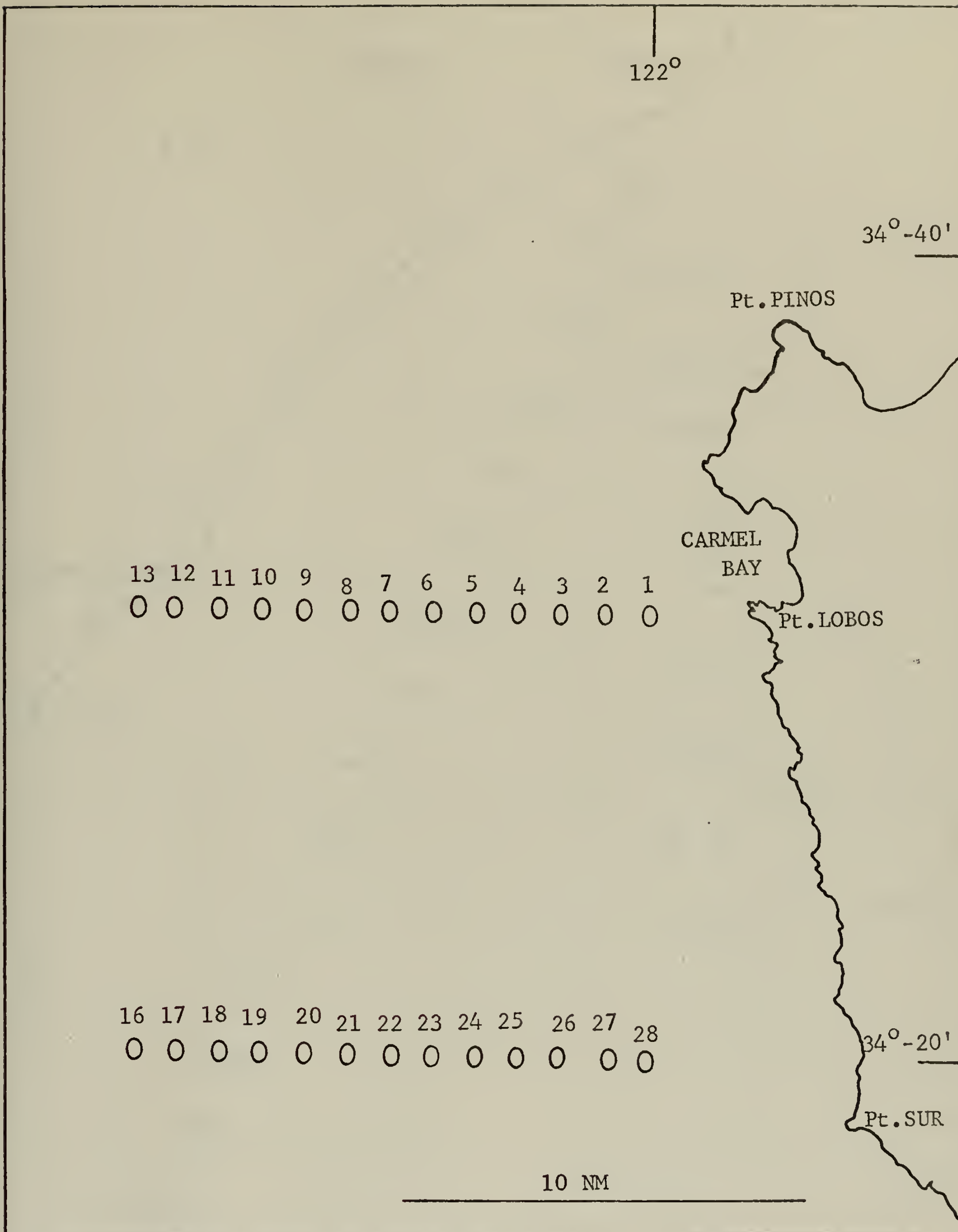

Figure 9. Chart of stations along sections 1 and 2.

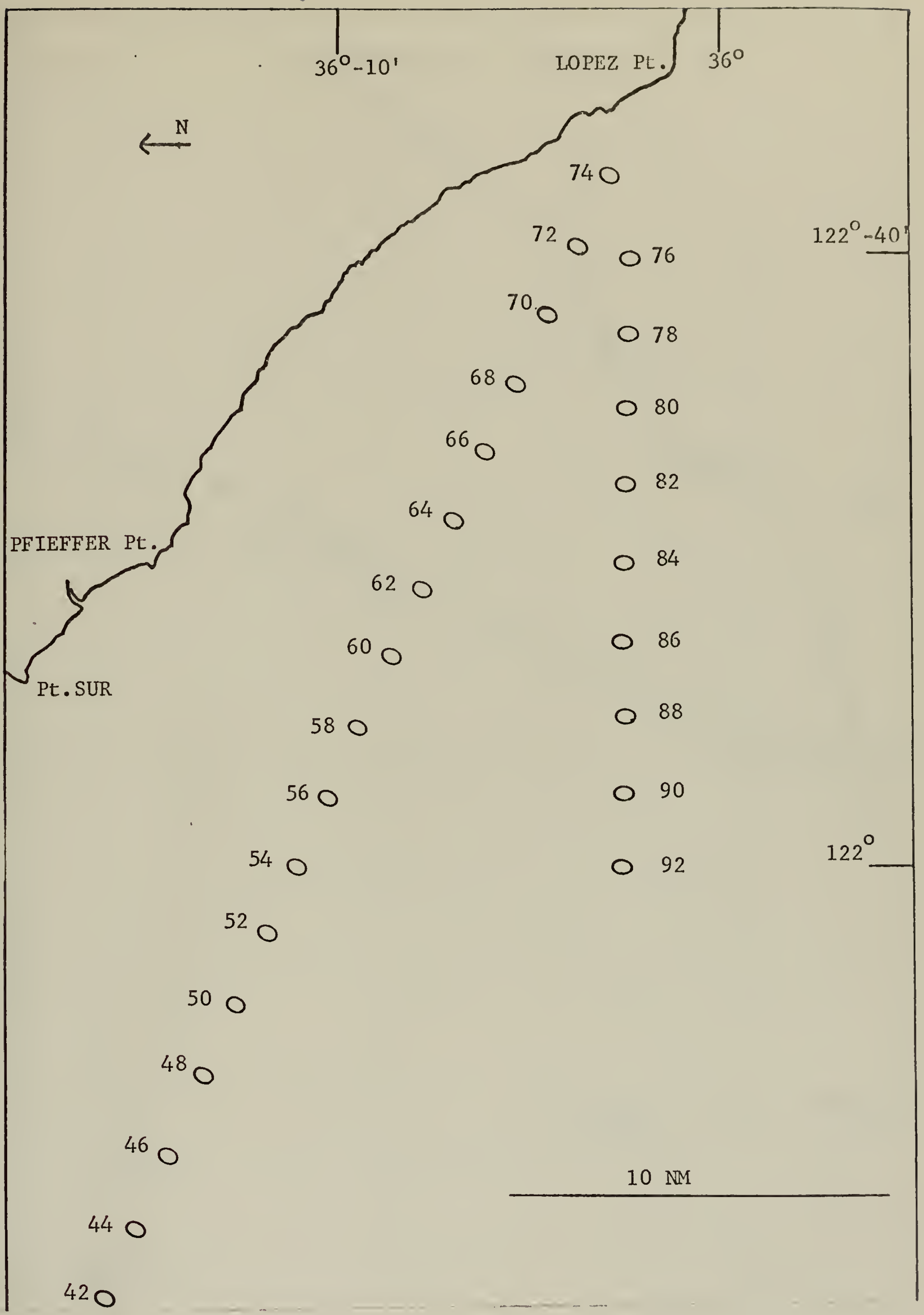

Figure 10. Chart of stations along sections 3 and 4.

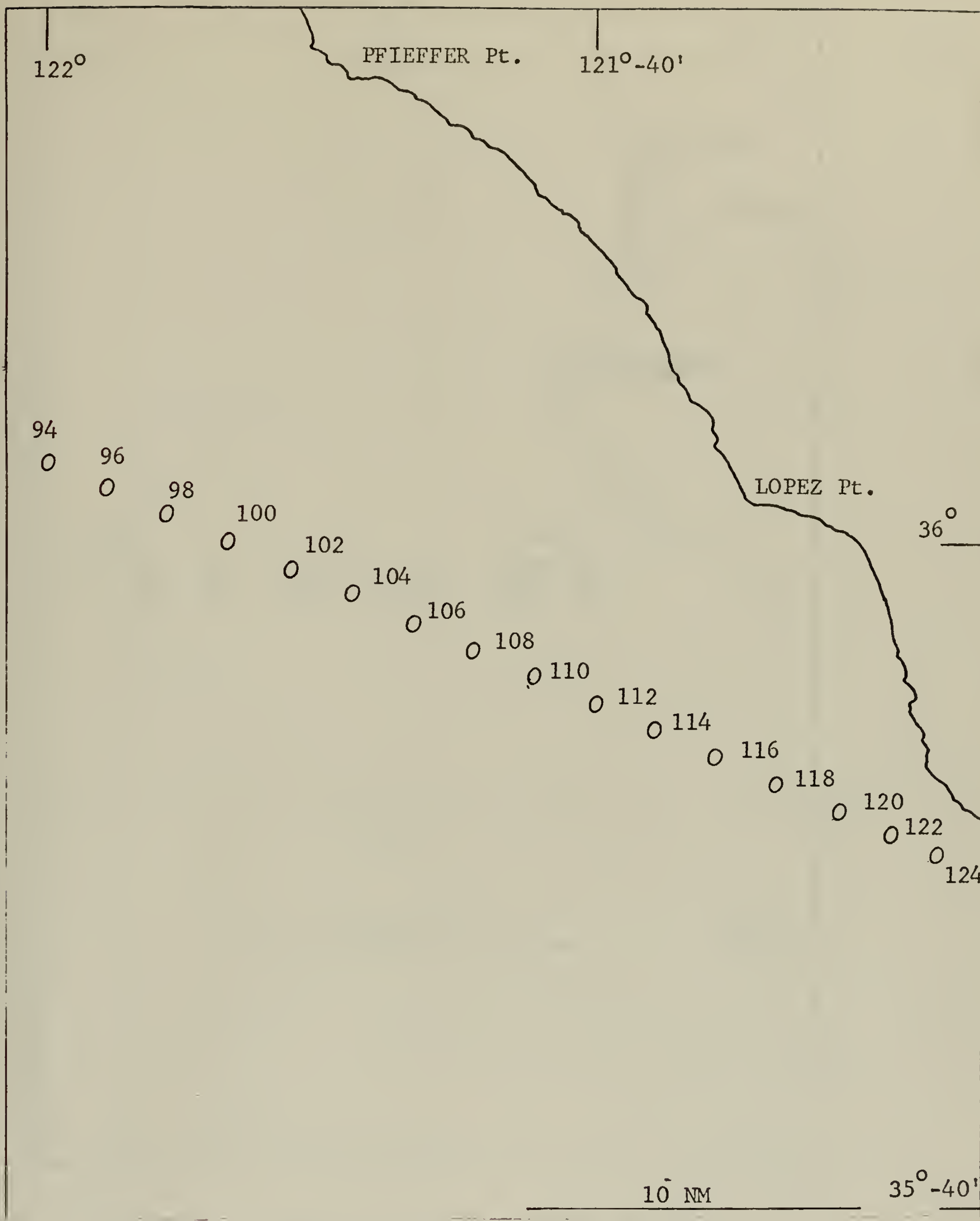

Figure 11. Chart of stations along section 5.

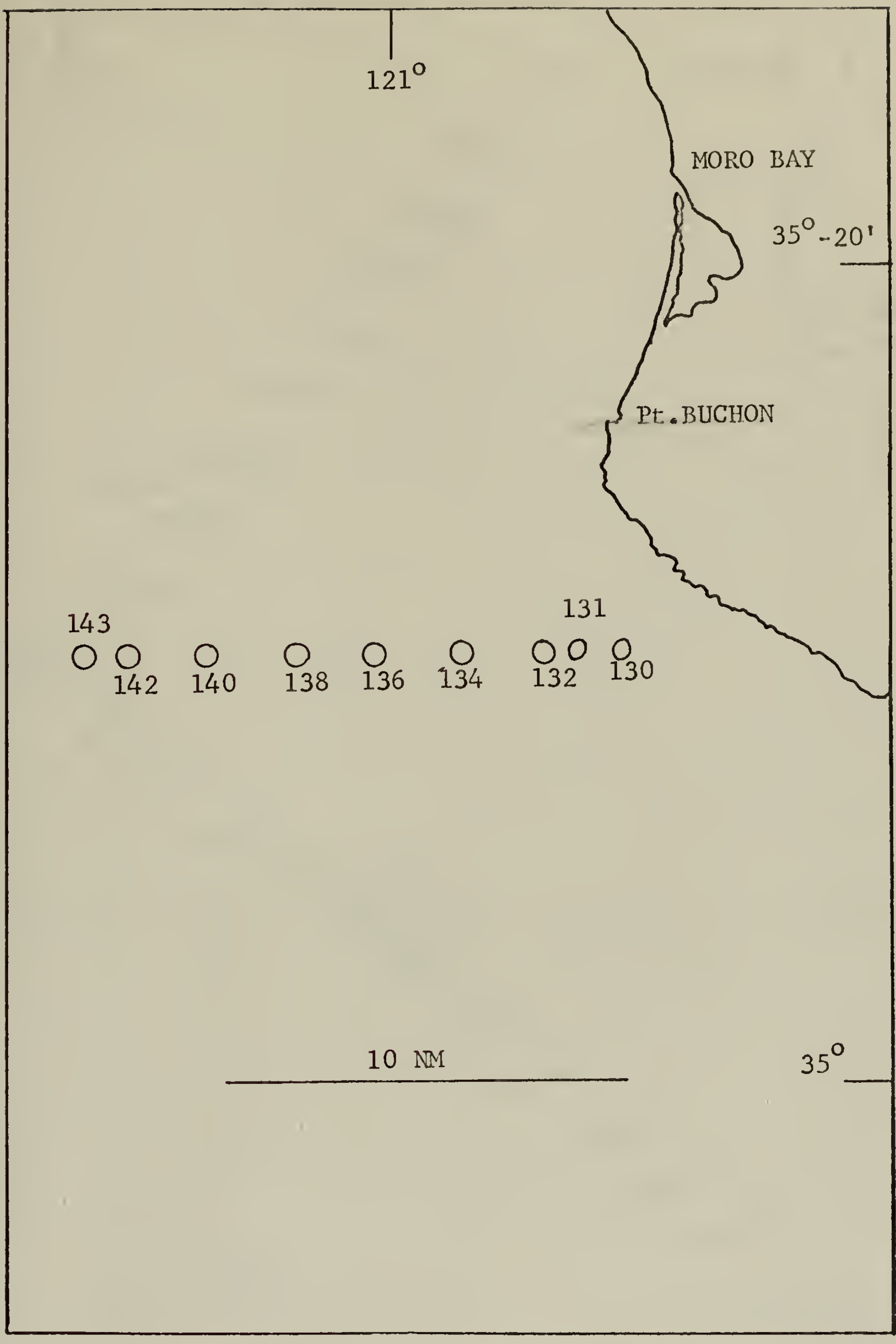

Figure 12. Chart of stations along section 6.

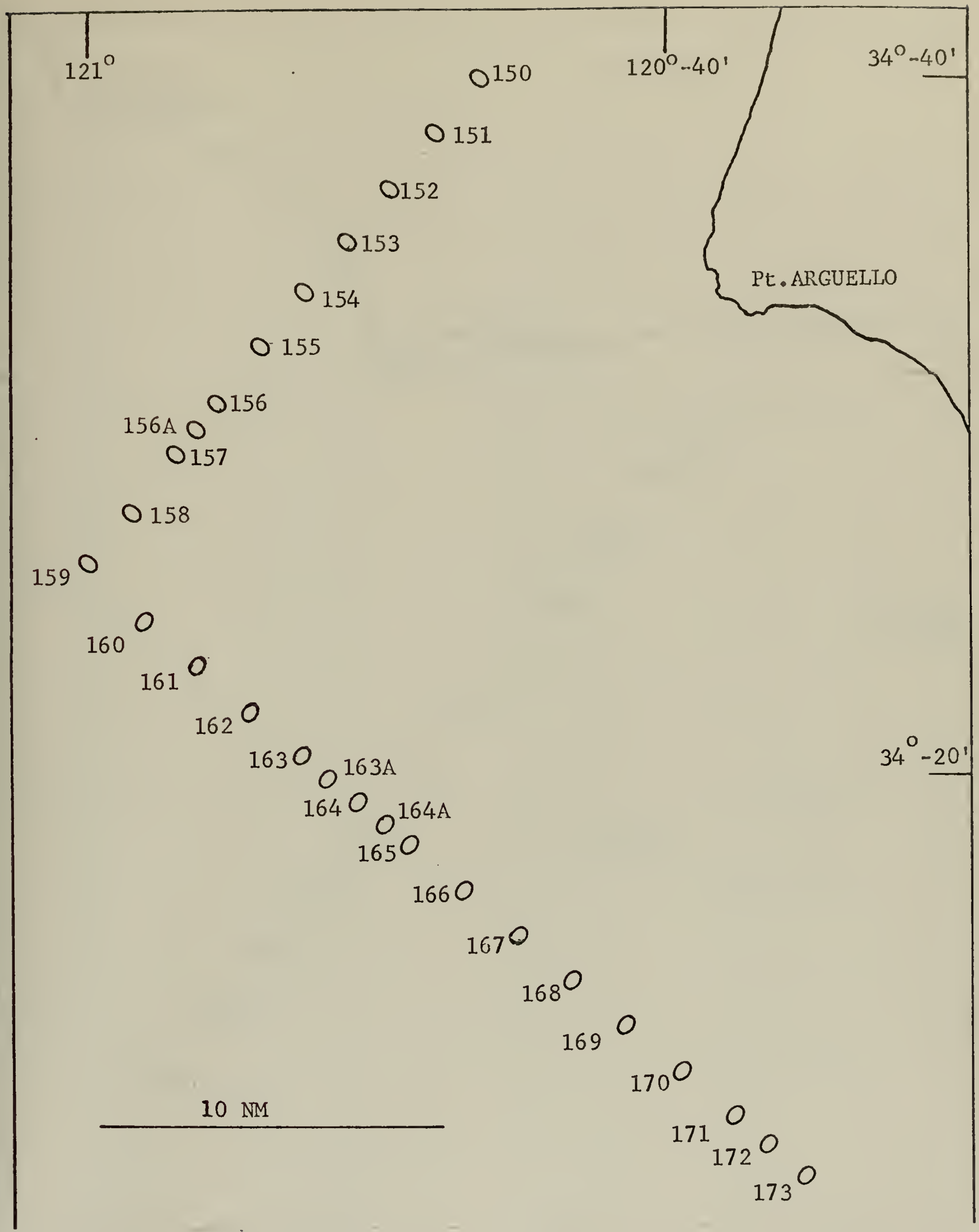

Figure 13. Chart of stations along sections 7 and 8.

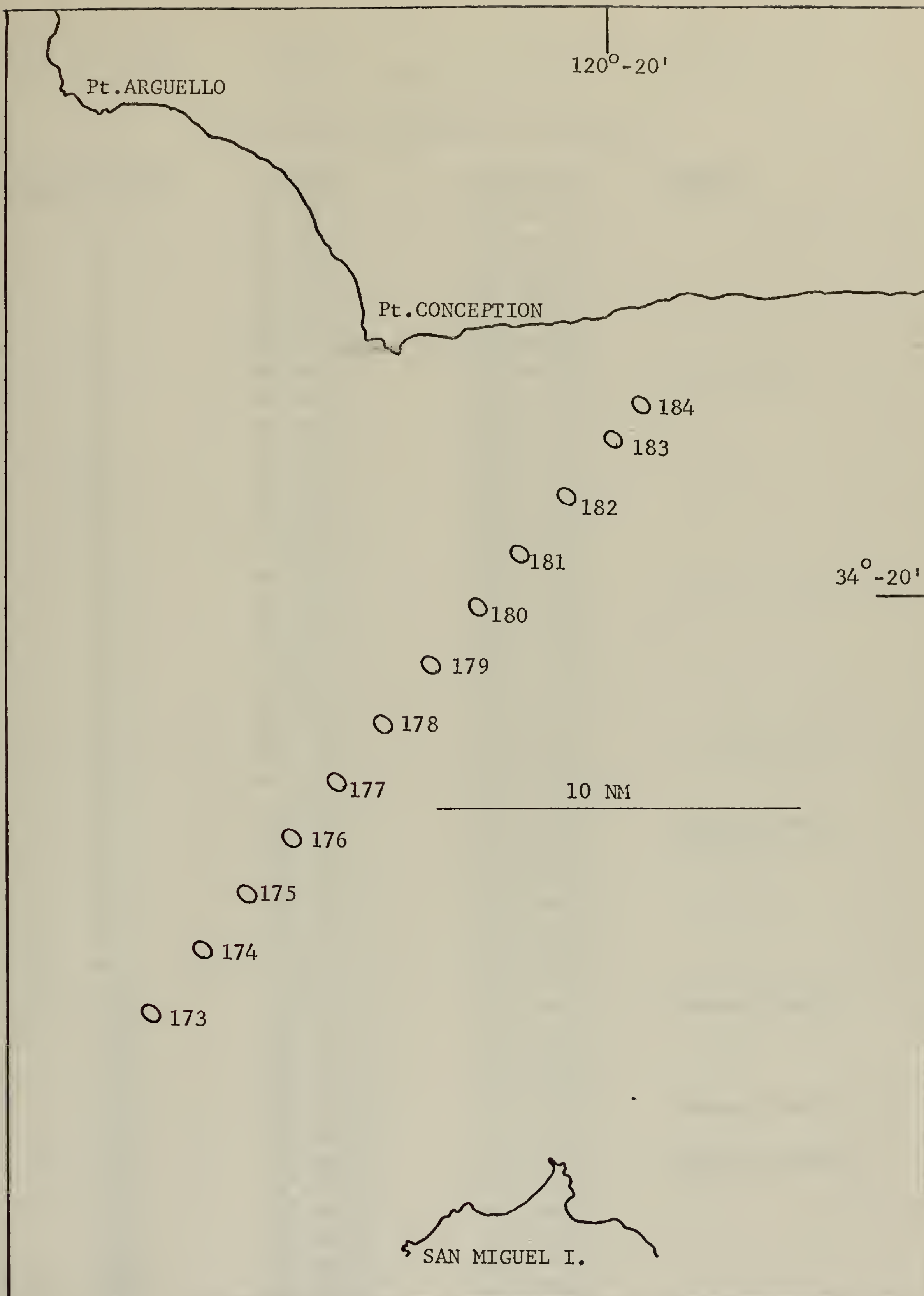

Figure 14. Chart of stations along section 9.

TABLE I

Latitude and Longitude of Stations

STATION NUMBER	LATITUDE	LONGITUDE	REMARKS
1.	36°-31.1'	122°-00.0'	
2.	36°-31.1'	122°-01.3'	
3.	36°-31.1'	122°-02.6'	
4.	36°-31.1'	122°-03.9'	
5.	36°-31.1'	122°-05.2'	
6.	36°-31.1'	122°-06.5'	
7.	36°-31.1'	122°-07.8'	
8.	36°-31.1'	122°-09.1'	
9.	36°-31.1'	122°-10.5'	
10.	36°-31.1'	122°-11.7'	
11.	36°-31.1'	122°-13.2'	
12.	36°-31.1'	122°-14.3'	
13.	36°-31.1'	122°-15.6'	
14.	36°-27.0'	122°-15.6'	
15.	36°-22.1'	122°-15.6'	
16.	36°-20.0'	122°-15.6'	
17.	36°-20.0'	122°-14.3'	
18.	36°-20.0'	122°-13.2'	
19.	36°-20.0'	122°-11.7'	
20.	36°-20.0'	122°-10.5'	
21.	36°-20.0'	122°-09.1'	
22.	36°-20.0'	122°-07.8'	
23.	36°-20.0'	122°-06.5'	
24.	36°-20.0'	122°-05.2'	
25.	36°-20.0'	122°-03.9'	Nansen Sample
26.	36°-20.0'	122°-02.6'	
27.	36°-20.0'	122°-01.3'	
28.	36°-20.0'	122°-00.0'	
42.	36°-16.3'	122°-14.3'	
44.	36°-15.3'	122°-11.8'	
46.	36°-14.5'	122°-09.4'	
48.	36°-13.6'	122°-06.9'	Nansen Sample
50.	36°-12.7'	122°-04.5'	
52.	36°-11.8'	122°-02.3'	
54.	36°-11.1'	122°-00.2'	
56.	36°-10.3'	121°-57.9'	Nansen Sample
58.	36°-09.4'	121°-55.6'	
60.	36°-08.5'	121°-53.3'	Nansen Sample
62.	36°-07.7'	121°-51.1'	
64.	36°-06.9'	121°-48.8'	
66.	36°-06.2'	121°-46.6'	
68.	36°-05.4'	121°-44.4'	
70.	36°-04.6'	121°-42.2'	
72.	36°-03.8'	121°-40.0'	Nansen Sample
76.	36°-02.4'	121°-37.7'	
78.	36°-02.4'	121°-40.2'	

STATION NUMBER	LATITUDE	LONGITUDE	REMARKS
80.	36°-02.4'	121°-42.7'	Nansen Sample
82.	36°-02.4'	121°-45.3'	
84.	36°-02.4'	121°-47.6'	
86.	36°-02.4'	121°-50.3'	
88.	36°-02.4'	121°-52.6'	
90.	36°-02.4'	121°-55.0'	Nansen Sample
92.	36°-02.4'	121°-57.4'	
94.	36°-02.4'	122°-00.0'	
96.	36°-01.7'	121°-57.7'	
98.	36°-00.8'	121°-55.6'	
100.	35°-59.6'	121°-53.2'	
102.	35°-58.7'	121°-51.0'	Nansen Sample
104.	35°-57.9'	121°-48.9'	
106.	35°-57.1'	121°-46.6'	
108.	35°-56.3'	121°-44.2'	
110.	35°-55.6'	121°-42.1'	
112.	35°-54.8'	121°-39.6'	
114.	35°-54.0'	121°-37.5'	
116.	35°-53.1'	121°-35.4'	
118.	35°-52.3'	121°-33.1'	
120.	35°-51.4'	121°-30.7'	Nansen Sample
122.	35°-51.2'	121°-28.9'	
124.	35°-50.5'	121°-27.3'	
131.	35°-10.7'	120°-54.5'	
132.	35°-10.7'	120°-55.6'	
134.	35°-10.7'	120°-58.2'	
136.	35°-10.7'	121°-00.6'	Nansen Sample
138.	35°-10.7'	121°-03.0'	
140.	35°-10.7'	121°-05.5'	
142.	35°-10.7'	121°-08.0'	
143.	35°-10.7'	121°-09.3'	
150.	34°-40.0'	120°-46.5'	
151.	34°-38.4'	120°-47.9'	
152.	34°-36.8'	120°-49.1'	
153.	34°-35.3'	120°-50.9'	
154.	34°-33.8'	120°-52.3'	
155.	34°-32.2'	120°-53.8'	
156.	34°-30.7'	120°-55.4'	Nansen Sample
156A.	34°-29.8'	120°-56.1'	
157.	34°-29.1'	120°-56.8'	
158.	34°-27.5'	120°-58.3'	
159.	34°-26.0'	120°-59.8'	
160.	34°-24.4'	120°-57.9'	
161.	34°-23.2'	120°-56.3'	
162.	34°-21.9'	120°-54.3'	
163.	34°-20.5'	120°-52.4'	
163A.	34°-19.6'	120°-51.5'	
164.	34°-19.2'	120°-50.6'	
164A.	34°-18.7'	120°-49.7'	
165.	34°-18.1'	120°-48.9'	
166.	34°-16.7'	120°-47.2'	

STATION NUMBER	LATITUDE	LONGITUDE	REMARKS
167.	34°-15.3'	120°-45.3'	
168.	34°-14.1'	120°-43.3'	
169.	34°-12.8'	120°-41.4'	
170.	34°-11.4'	120°-39.6'	
171.	34°-10.2'	120°-37.8'	
172.	34°-09.4'	120°-36.5'	Nansen Sample
173.	34°-08.5'	120°-34.9'	
174.	34°-10.3'	120°-33.4'	
175.	34°-11.8'	120°-31.7'	
176.	34°-13.4'	120°-30.3'	
177.	34°-15.0'	120°-29.0'	
178.	34°-16.6'	120°-27.3'	
179.	34°-18.0'	120°-25.7'	
180.	34°-19.6'	120°-24.3'	
181.	34°-21.1'	120°-22.7'	
182.	34°-22.7'	120°-21.3'	
183.	34°-23.3'	120°-19.6'	
184.	34°-25.2'	120°-18.7'	

III. RESULTS

A. DISTRIBUTION OF TEMPERATURE AND SALINITY ALONG SECTIONS

The distribution of temperature and salinity for each of the nine sections is shown in Figures 15-32. Areas where isohaline or isothermal lines vanish indicate that these particular temperatures or salinities were not found at the particular stations because the casts were not deep enough. For all sections except section eight, the coastward direction is to the right on the diagrams. Section eight has the channel islands on the right.

One should note the possibility that some of the variations in the depth of the isopleths may be due to vertical motion of the water perhaps in the form of internal waves. Figures 15 and 17 show an apparent cyclic motion in several of the isopleths which is suspicious. However, this motion was apparent at approximately the same relative distance from the coast at two sections separated by 11.1 minutes of latitude (11.1 NM) and nearly ten hours in time so the cause may be horizontal difference in the character of the water at that distance from the coast rather than vertical motion. The sections do generally indicate warmer, saltier water near the coastline, an apparent sign that northward flow is intruding. Also notable is the obviously different water encountered when traversing sections seven and eight (Figures 27-30).

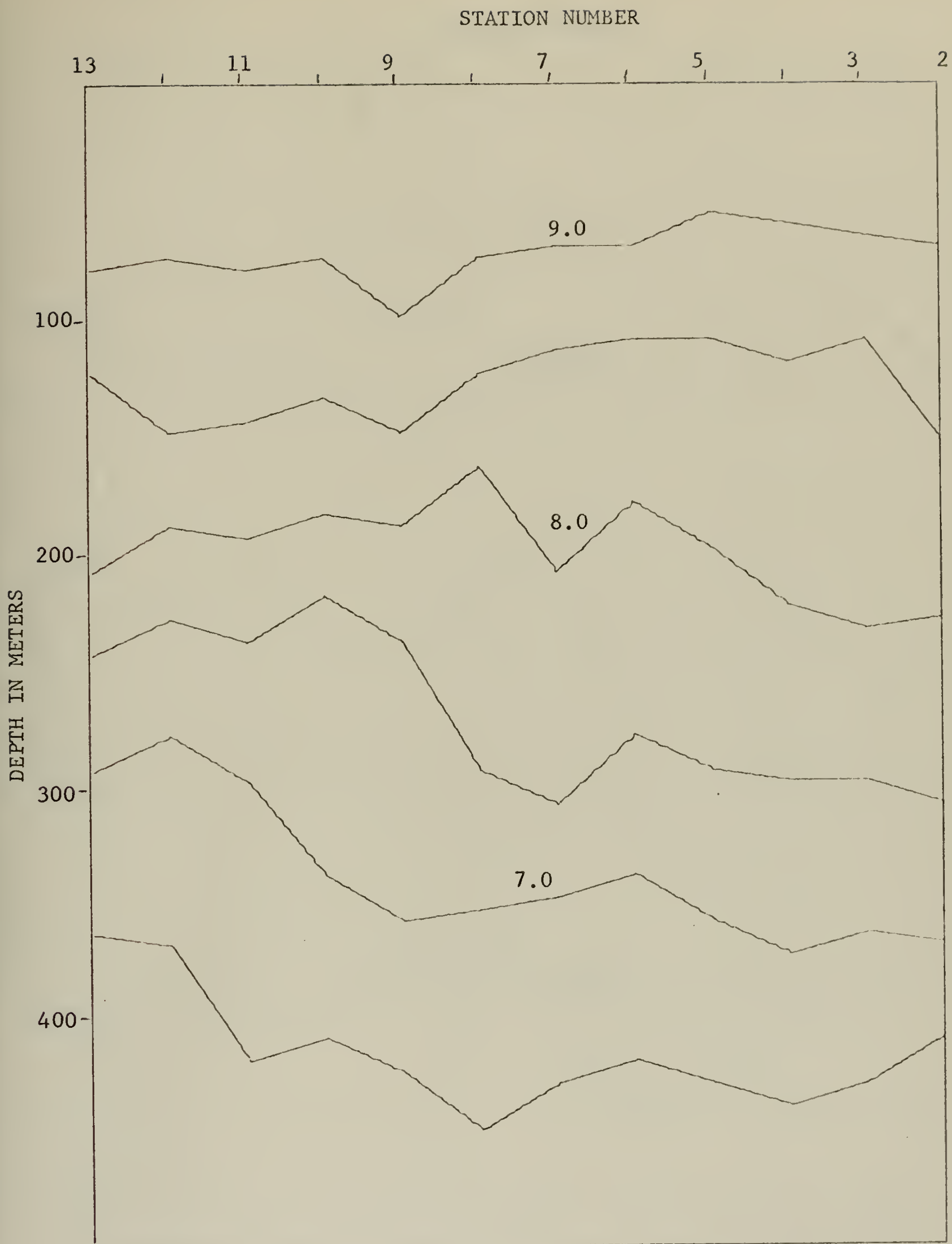

Figure 15. Distribution of temperature (^{o}C), section 1.

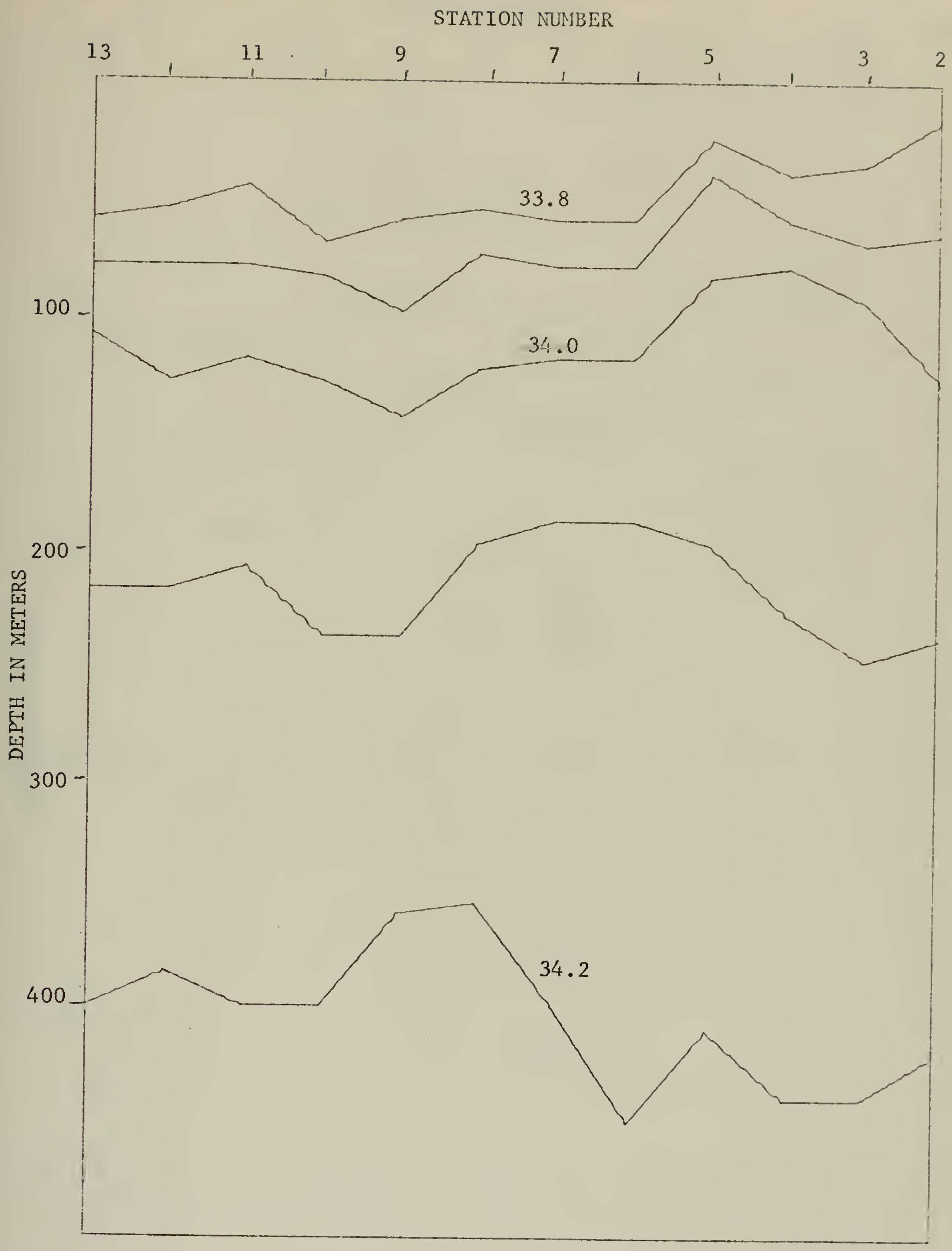

Figure 16. Distribution of salinity (ppt), section 1.

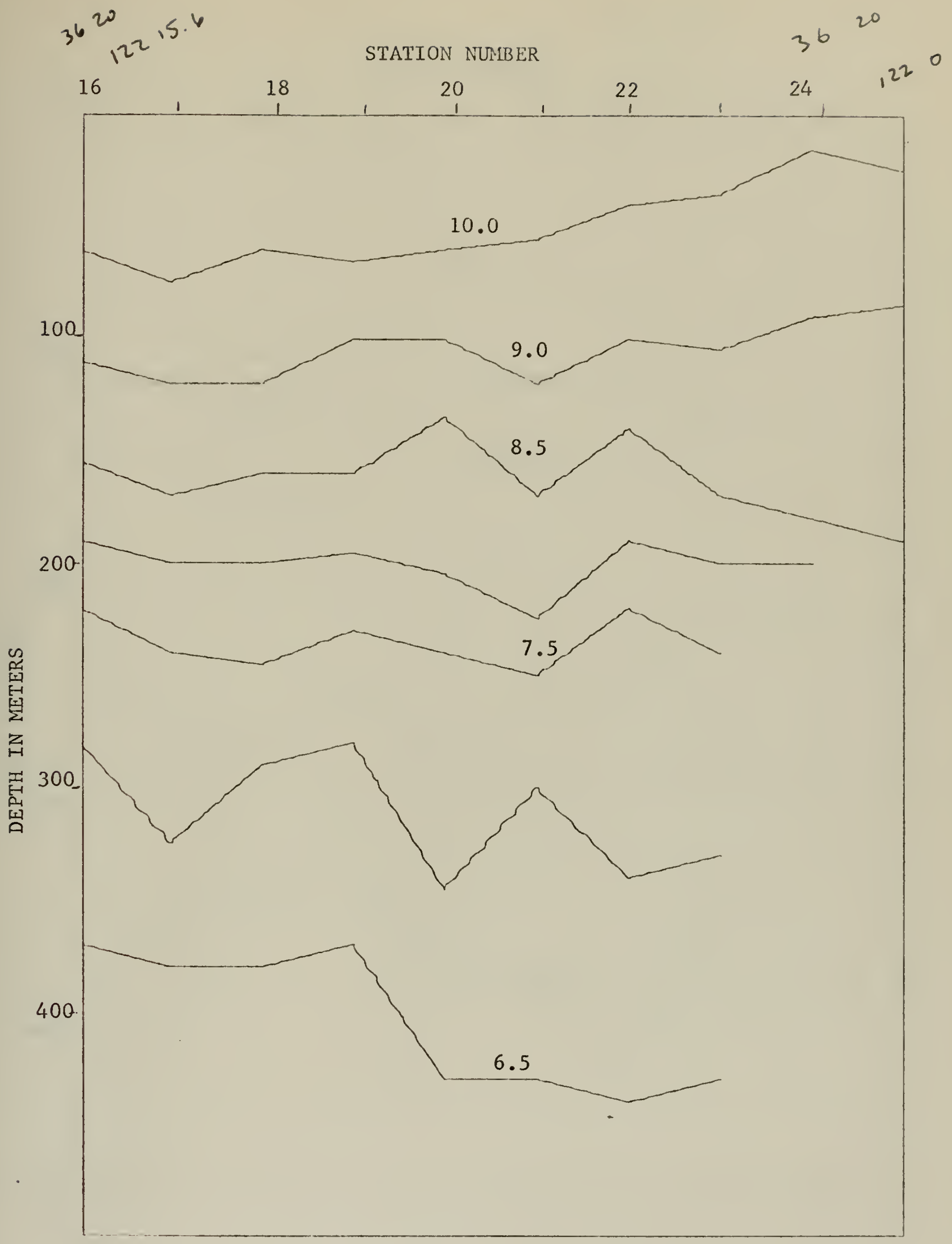

Figure 17. Distribution of temperature ($^{\circ}C$), section 2.

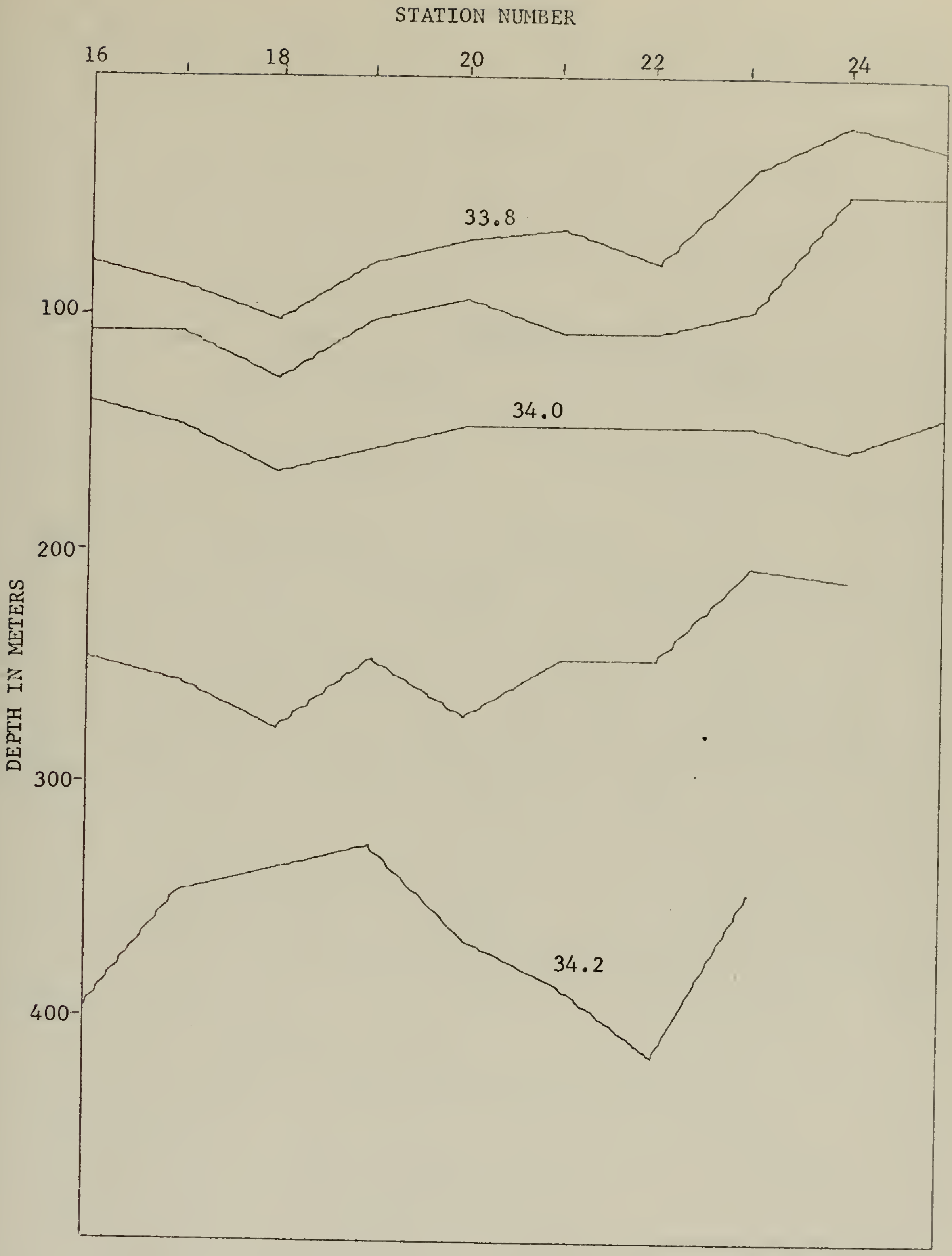

Figure 18. Distribution of salinity (ppt), section 2.

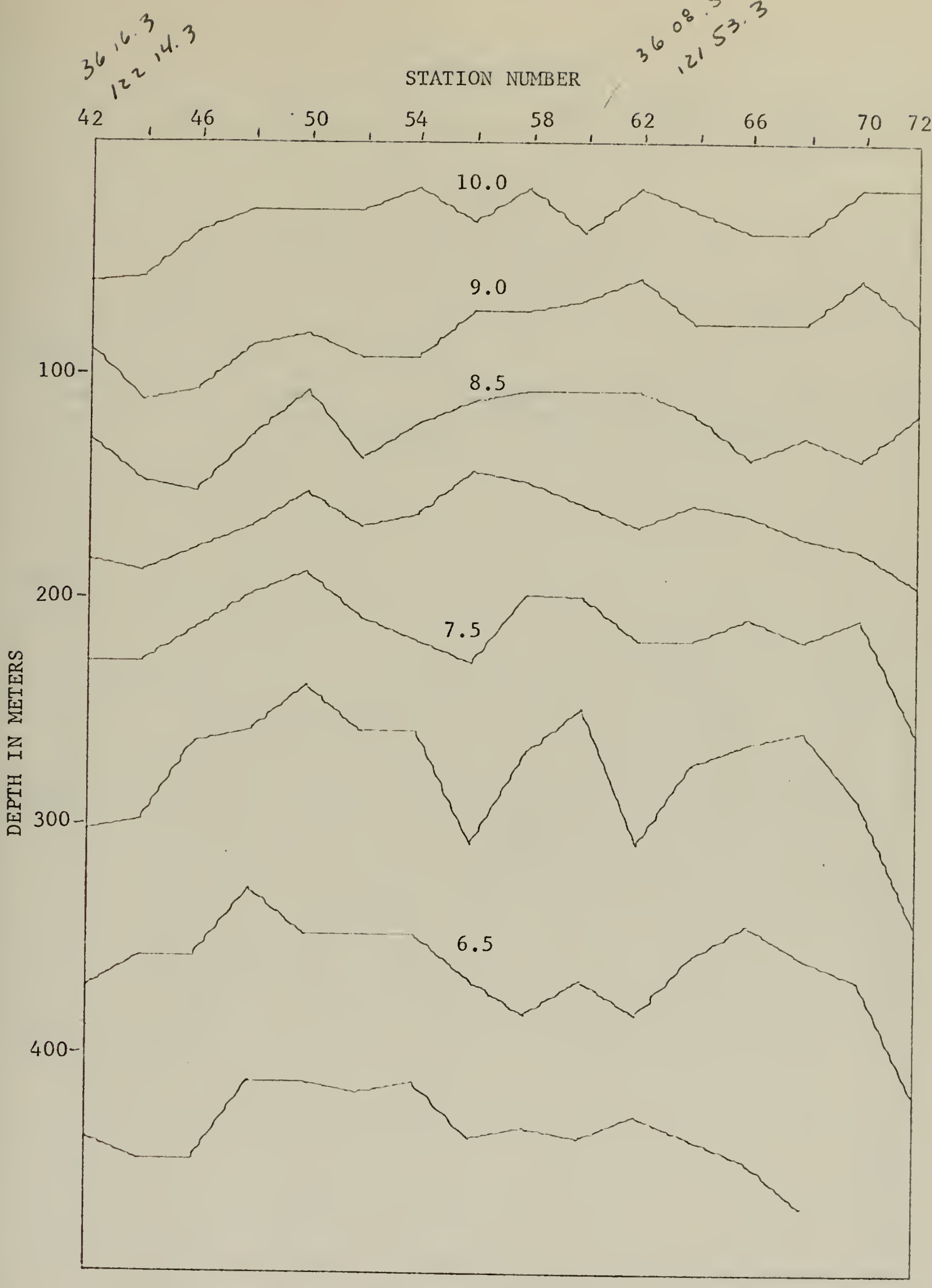

Figure 19. Distribution of temperature (°C), section 3.

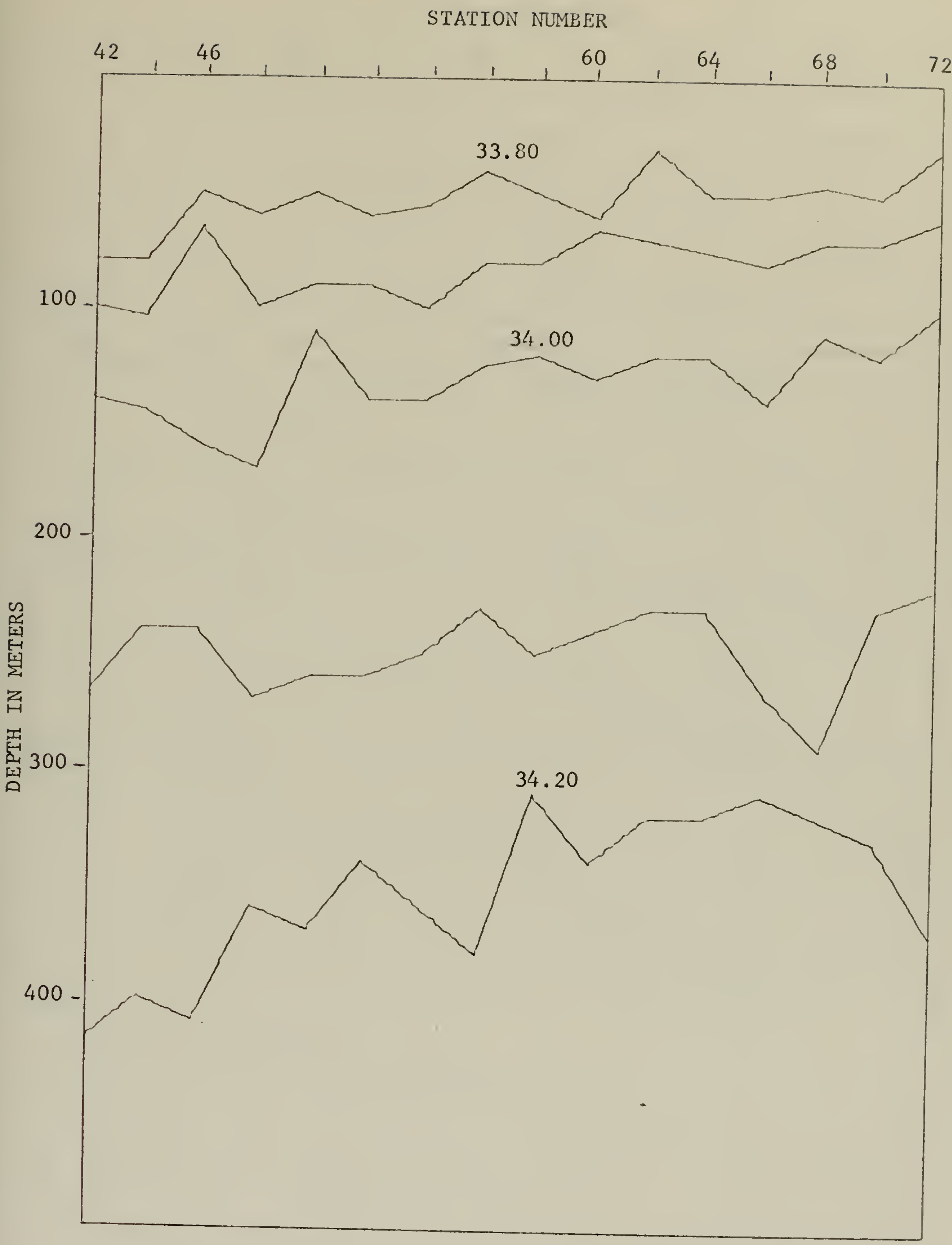

Figure 20. Distribution of salinity (ppt), section 3.

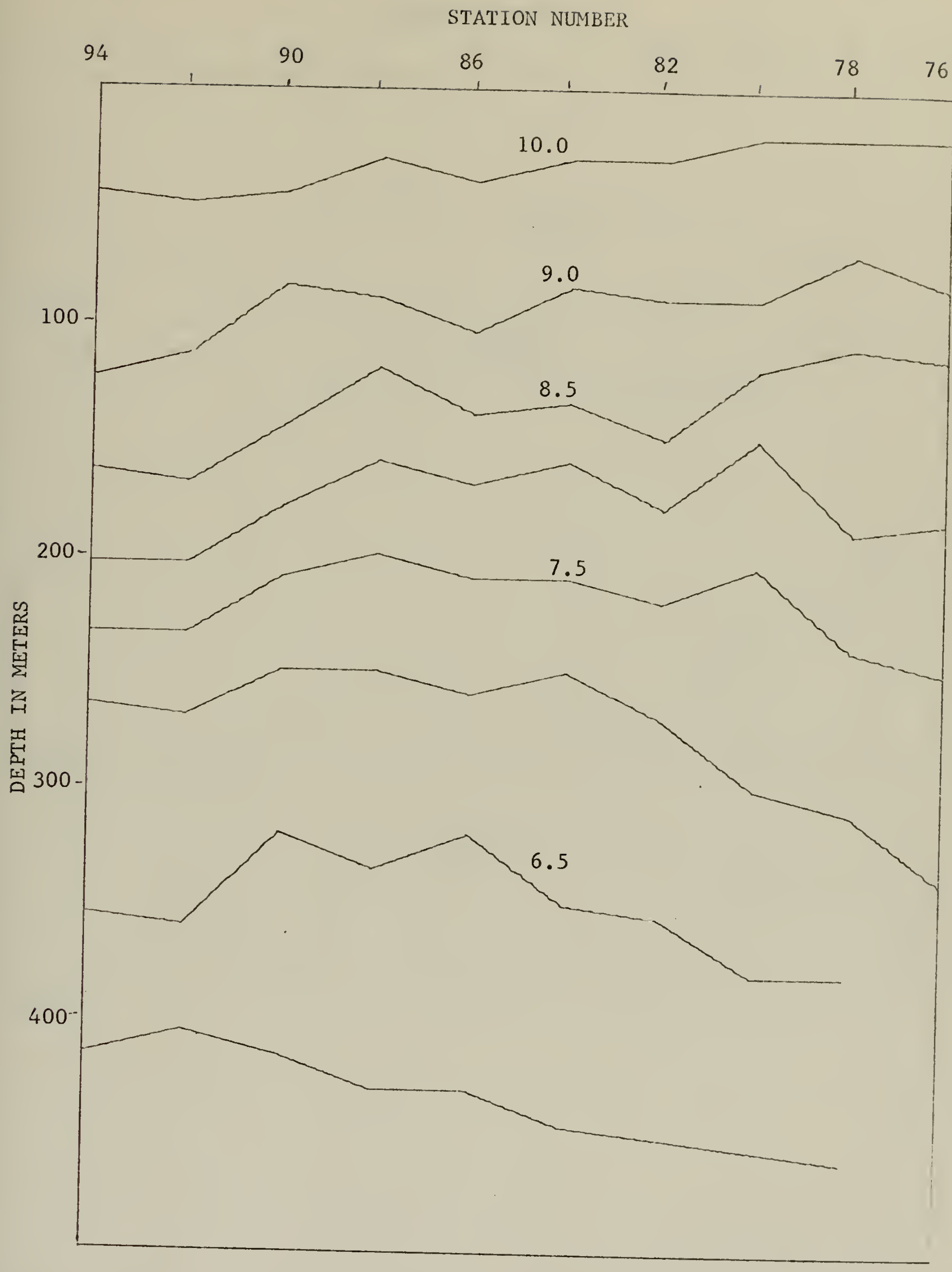

Figure 21. Distribution of temperature (°C), section 4.

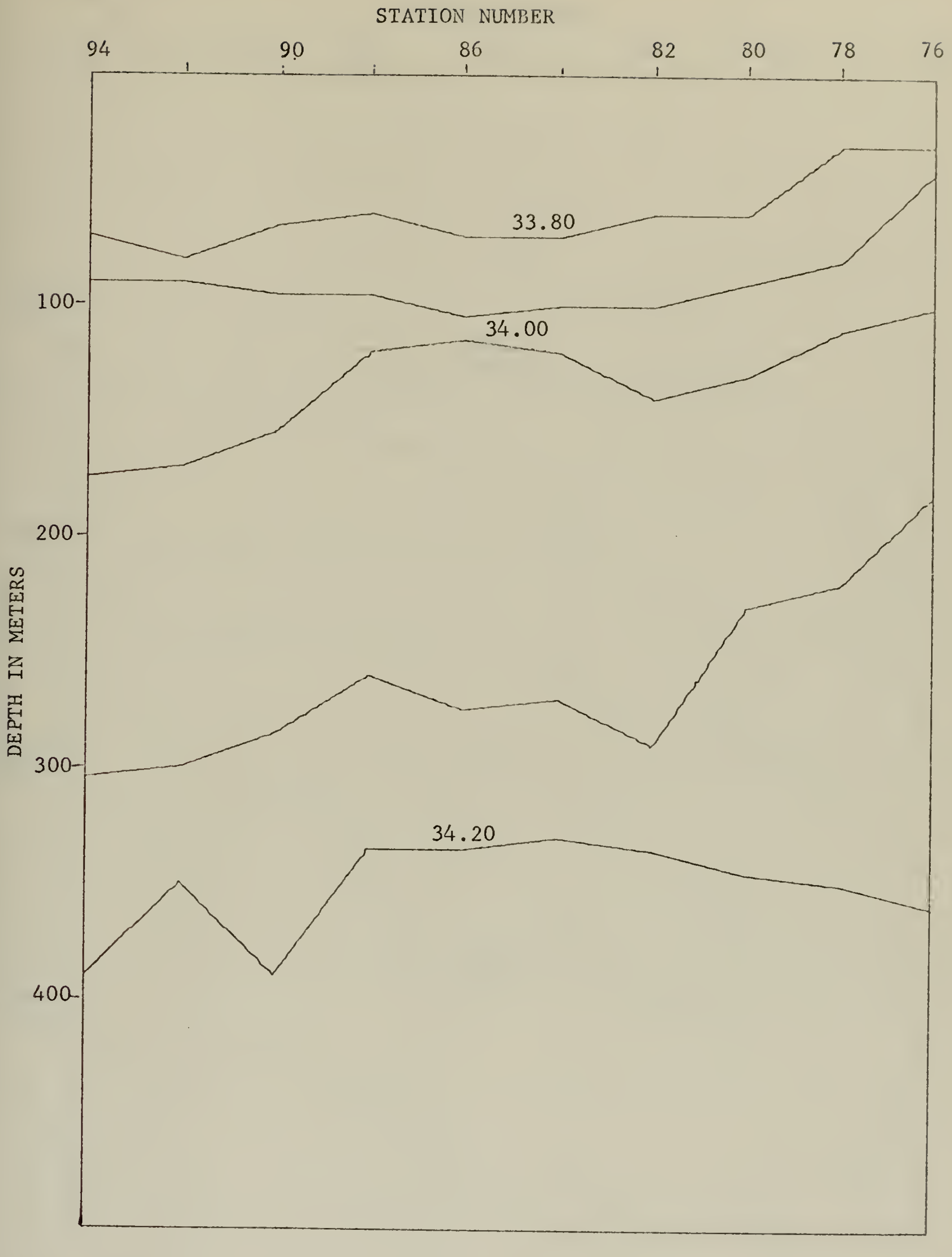

Figure 22. Distribution of salinity (ppt), section 4.

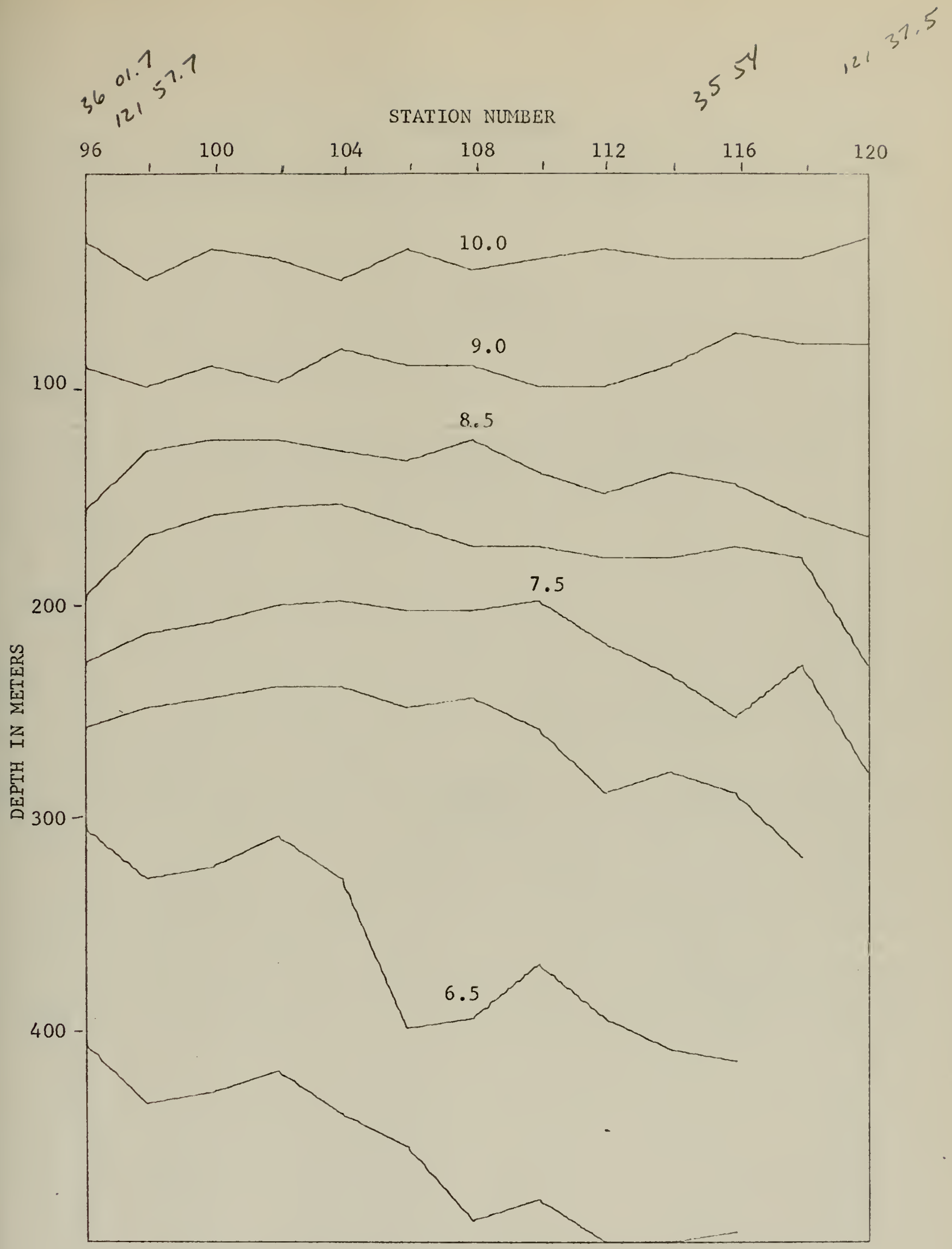

Figure 23. Distribution of temperature ($^{\circ}C$), section 5.

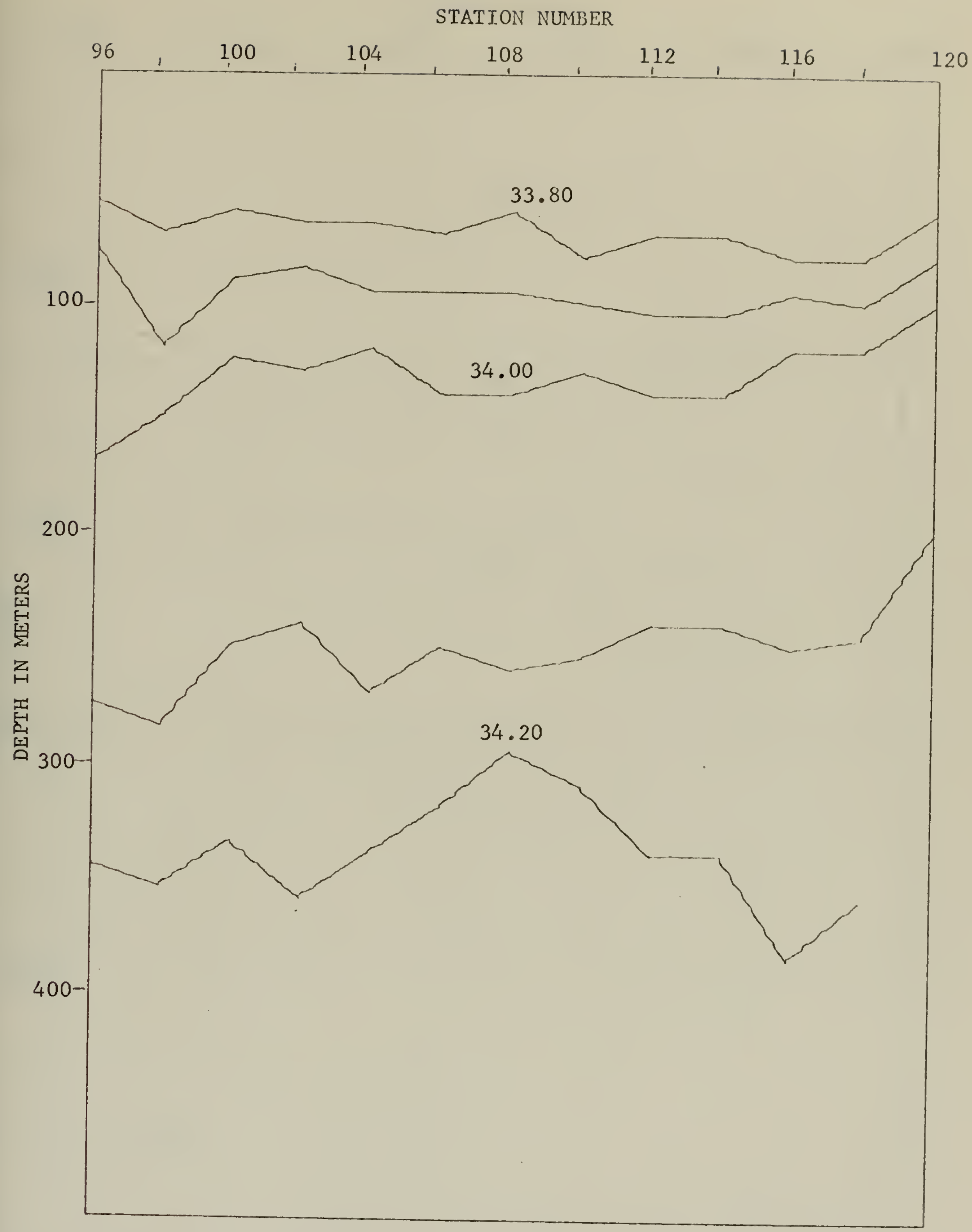

Figure 24. Distribution of salinity (ppt), section 5.

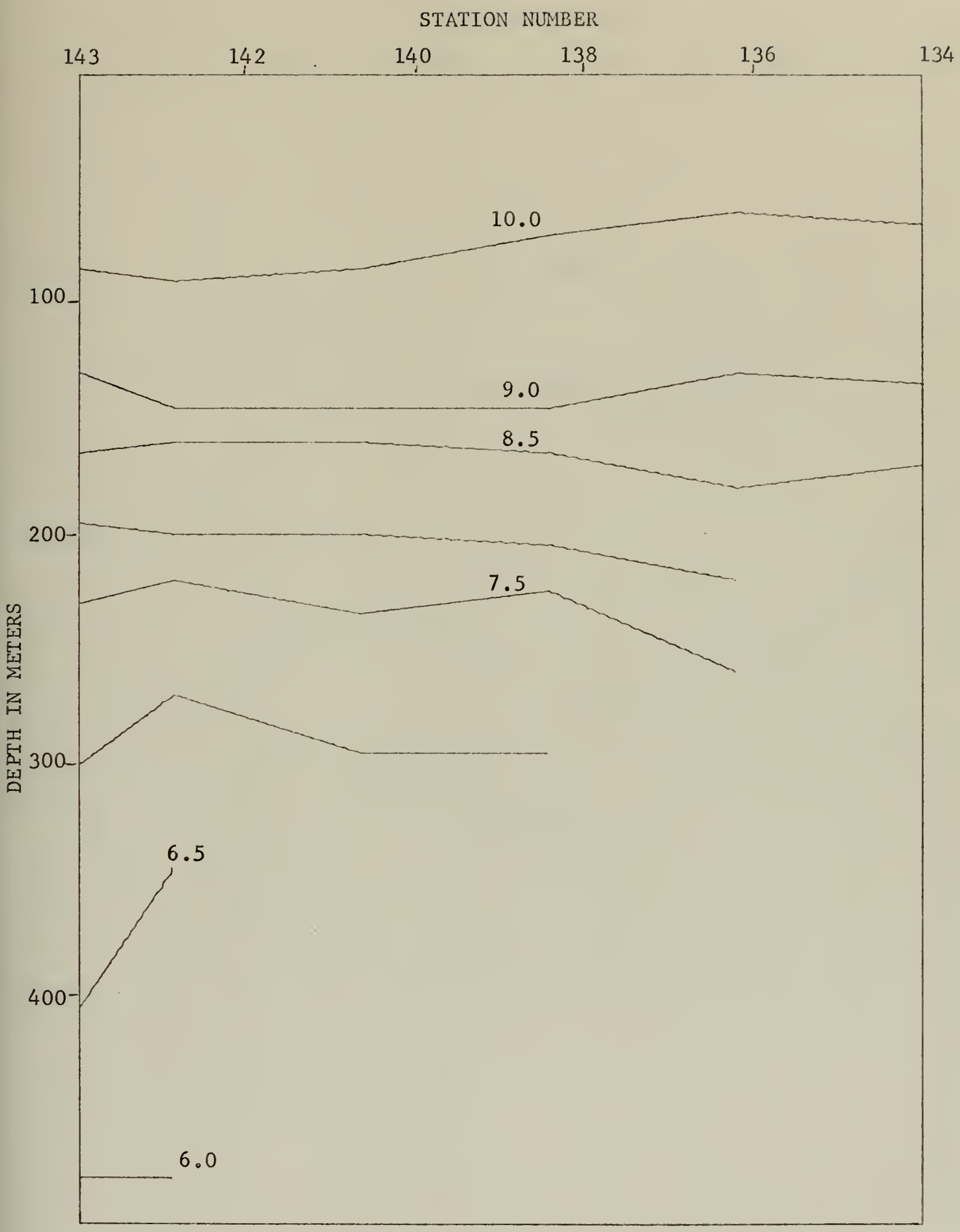

Figure 25. Distribution of temperature (°C), section 6.

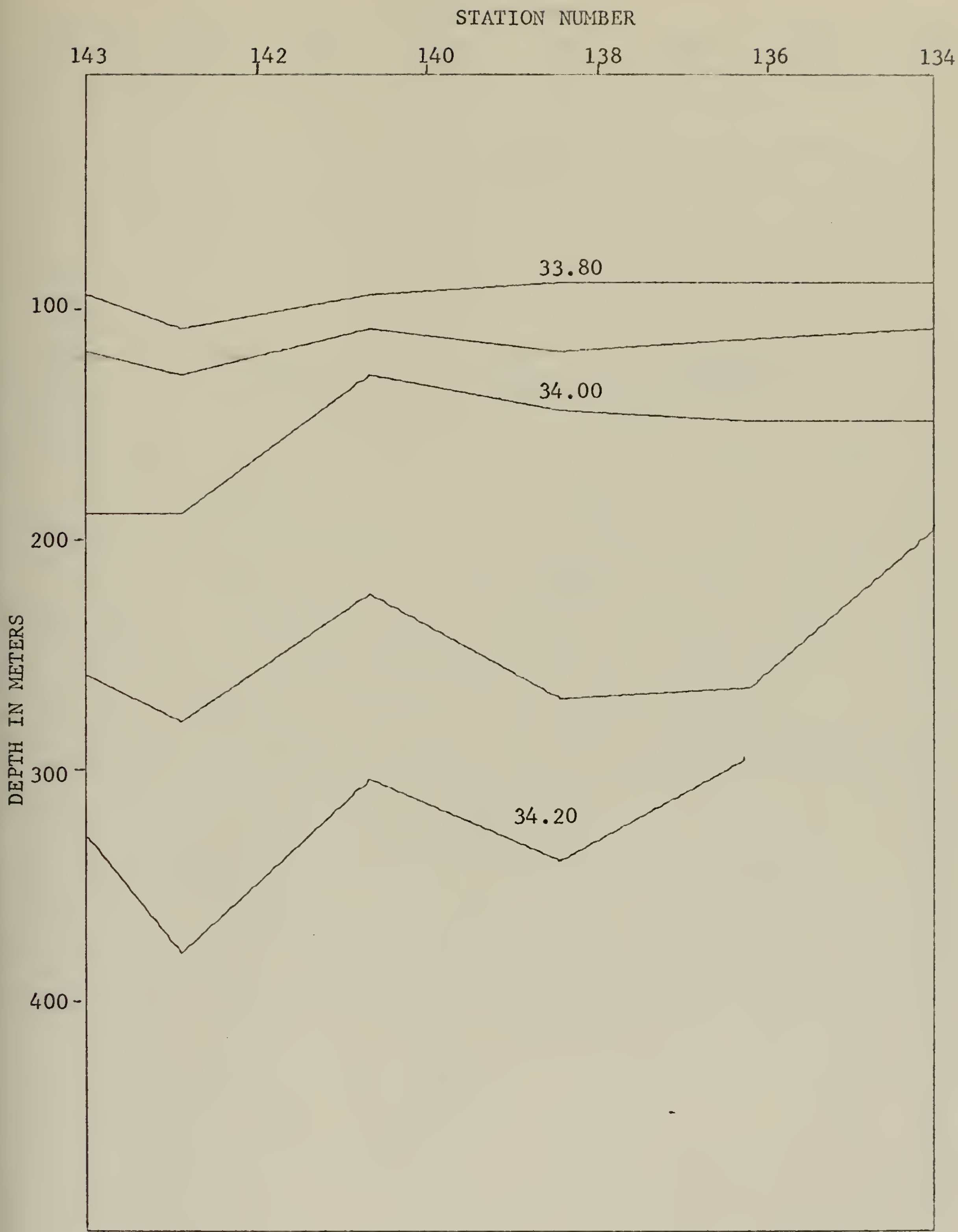

Figure 26. Distribution of salinity (ppt), section 6.

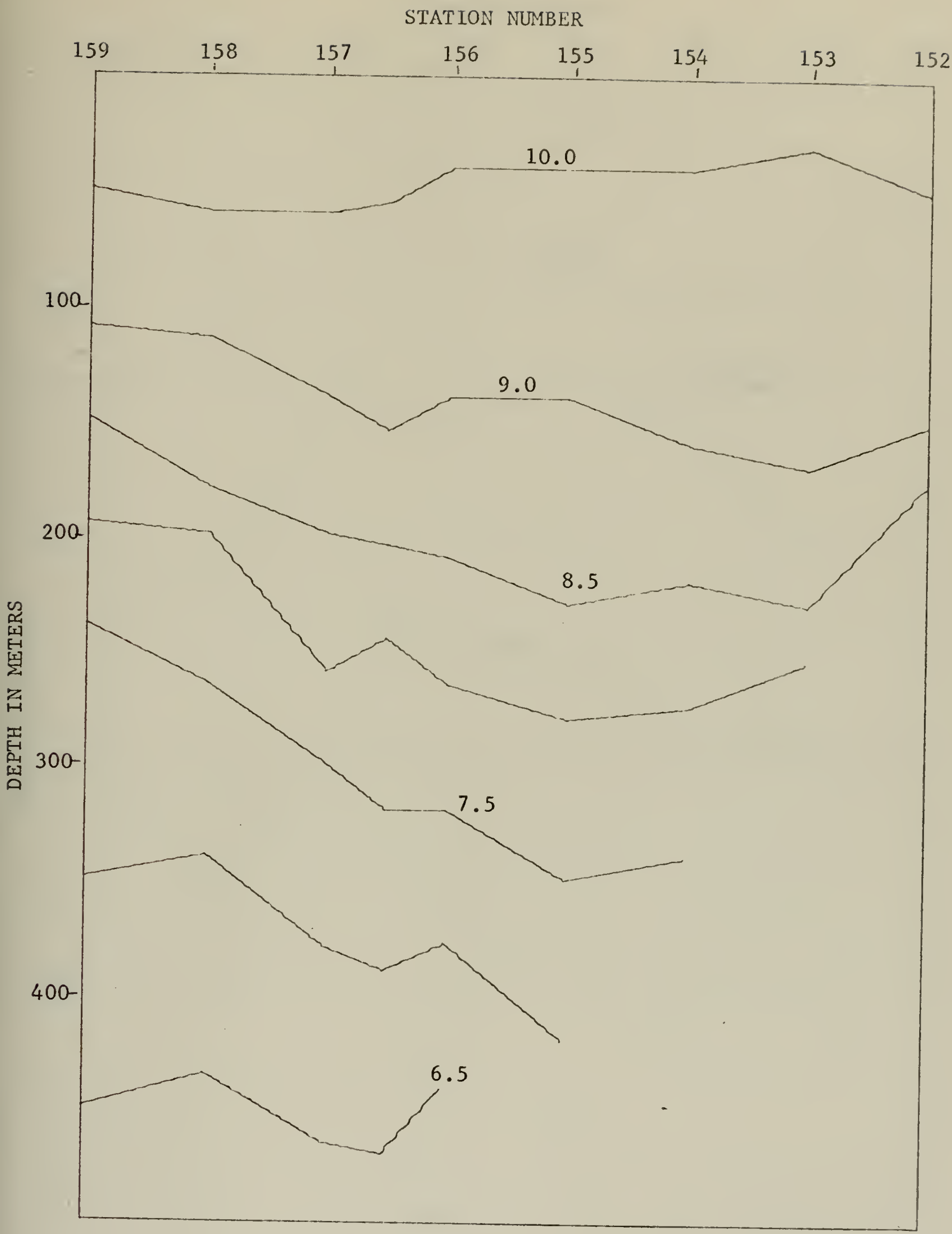

Figure 27. Distribution of temperature (^{o}C), section 7.

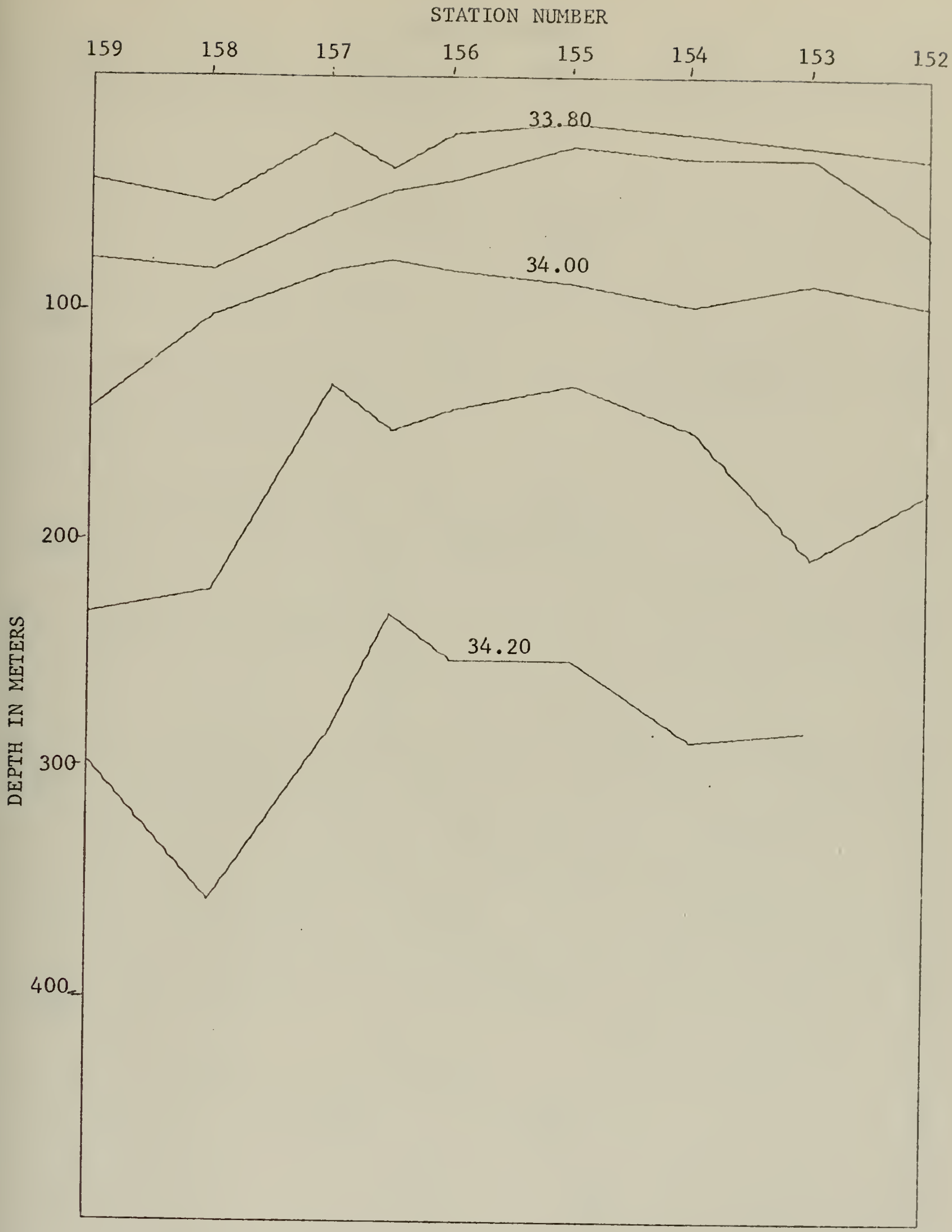

Figure 28. Distribution of salinity (ppt), section 7.

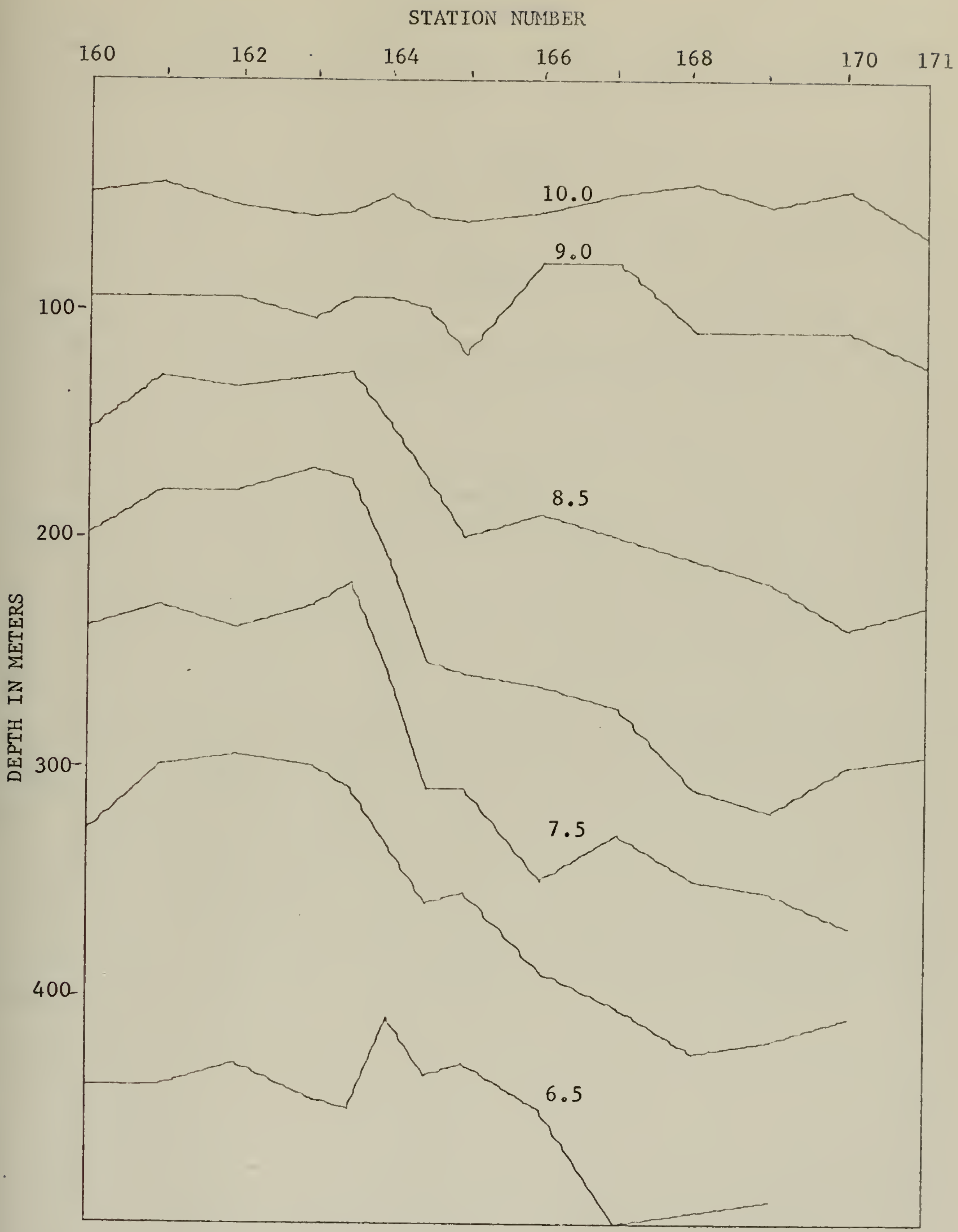

Figure 29. Distribution of temperature (°C), section 8.

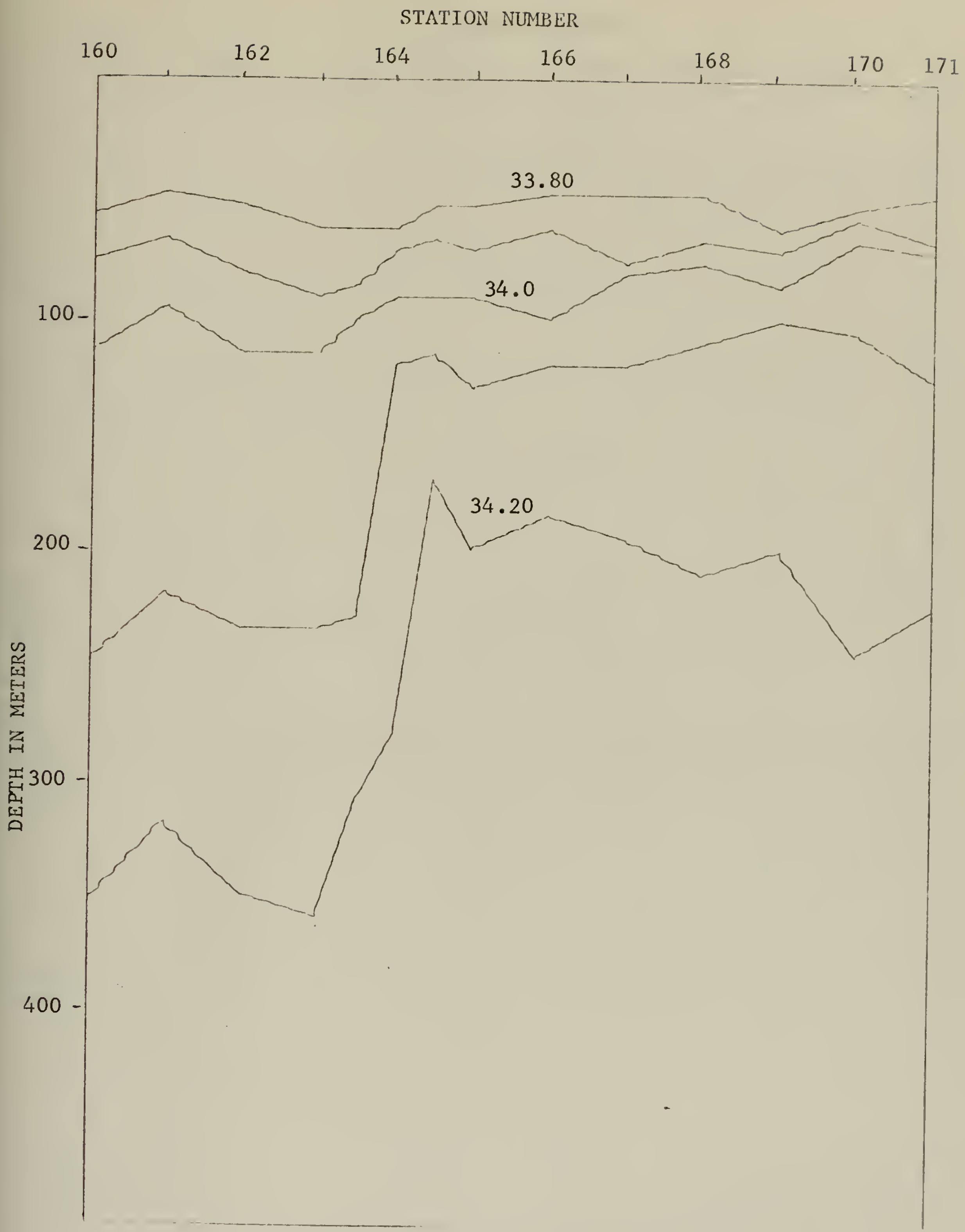

Figure 30. Distribution of salinity (ppt), section 8.

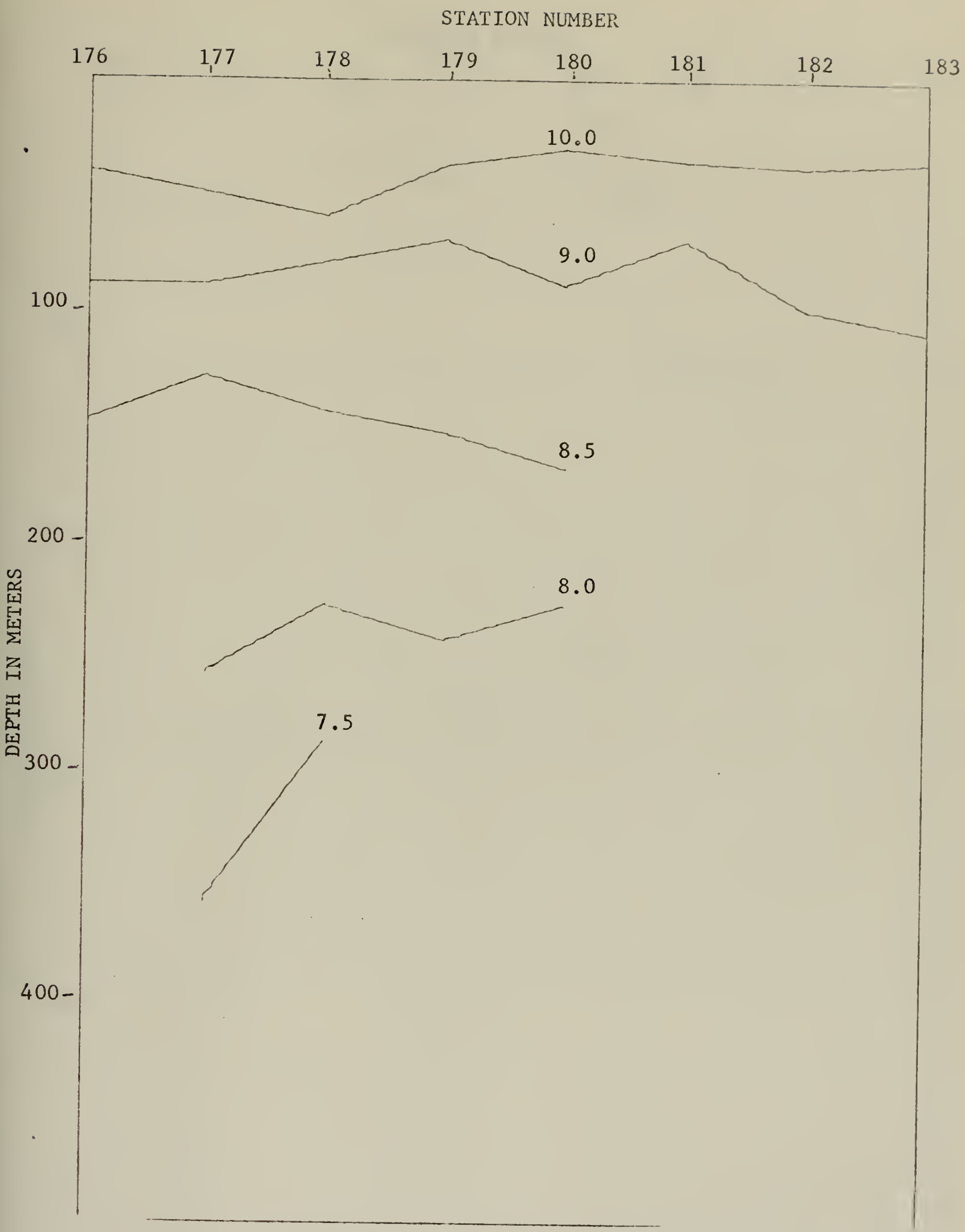

Figure 31. Distribution of temperature (^{o}C), section 9.

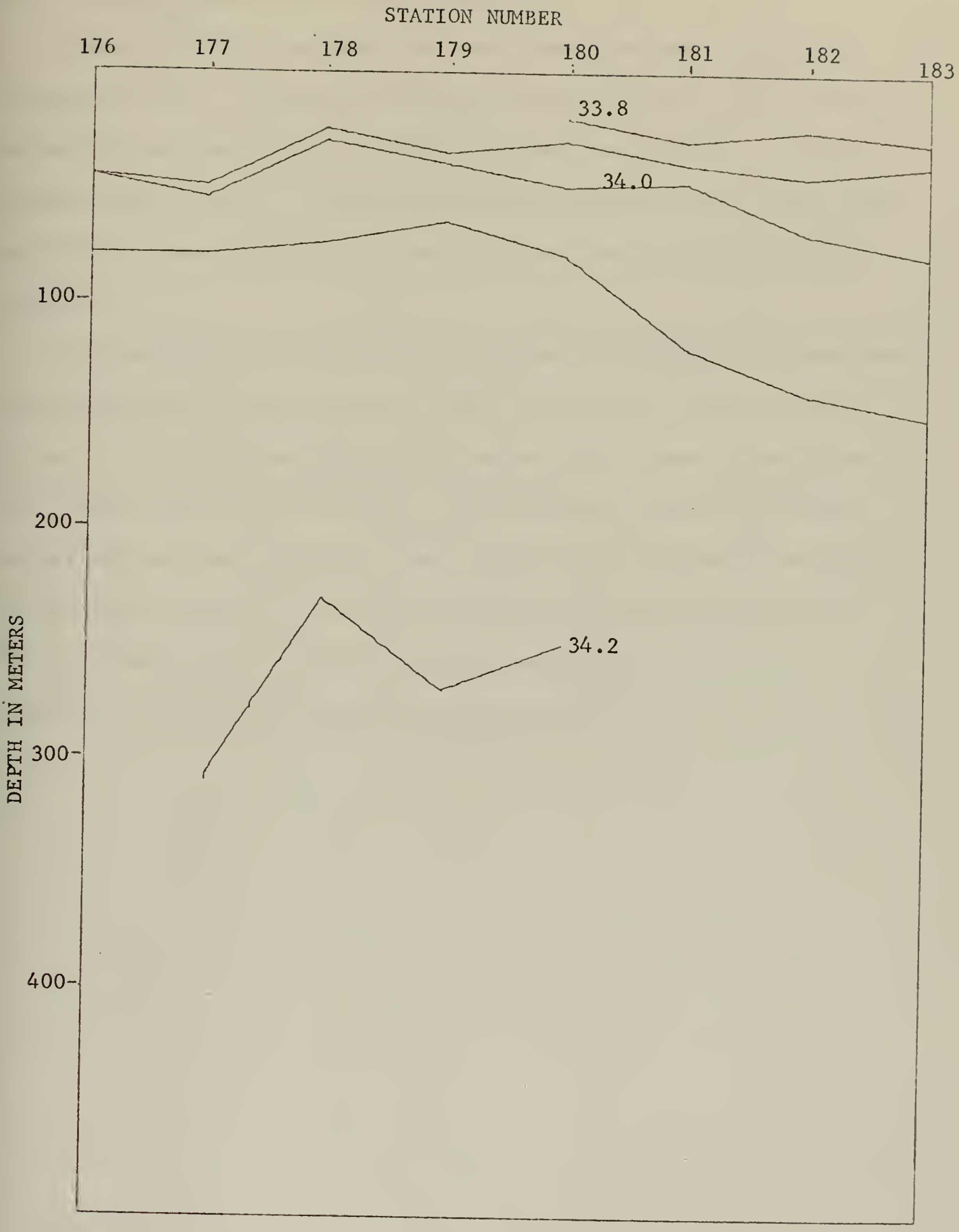

Figure 32. Distribution of salinity (ppt), section 9.

B. SV/STD RECORD FROM EACH SECTION

Sample SV/STD records for each section are shown in Figures 33-41. These are photographs of the actual charts obtained on the cruise. Depths shown are correct for the temperature trace; 25 meters should be subtracted from the salinity trace reading to get correct depth for salinity values.

The particular charts were chosen to show the occurrence of temperature inversions at all sections. The salinity trace shows fluctuations associated with these inversions, but they are not as obvious. The larger spikes of noise apparent on the salinity trace have been discussed earlier; other noise may be caused by additional amplifiers which technicians had installed in the equipment aboard ship to correct a salinity channel malfunction.

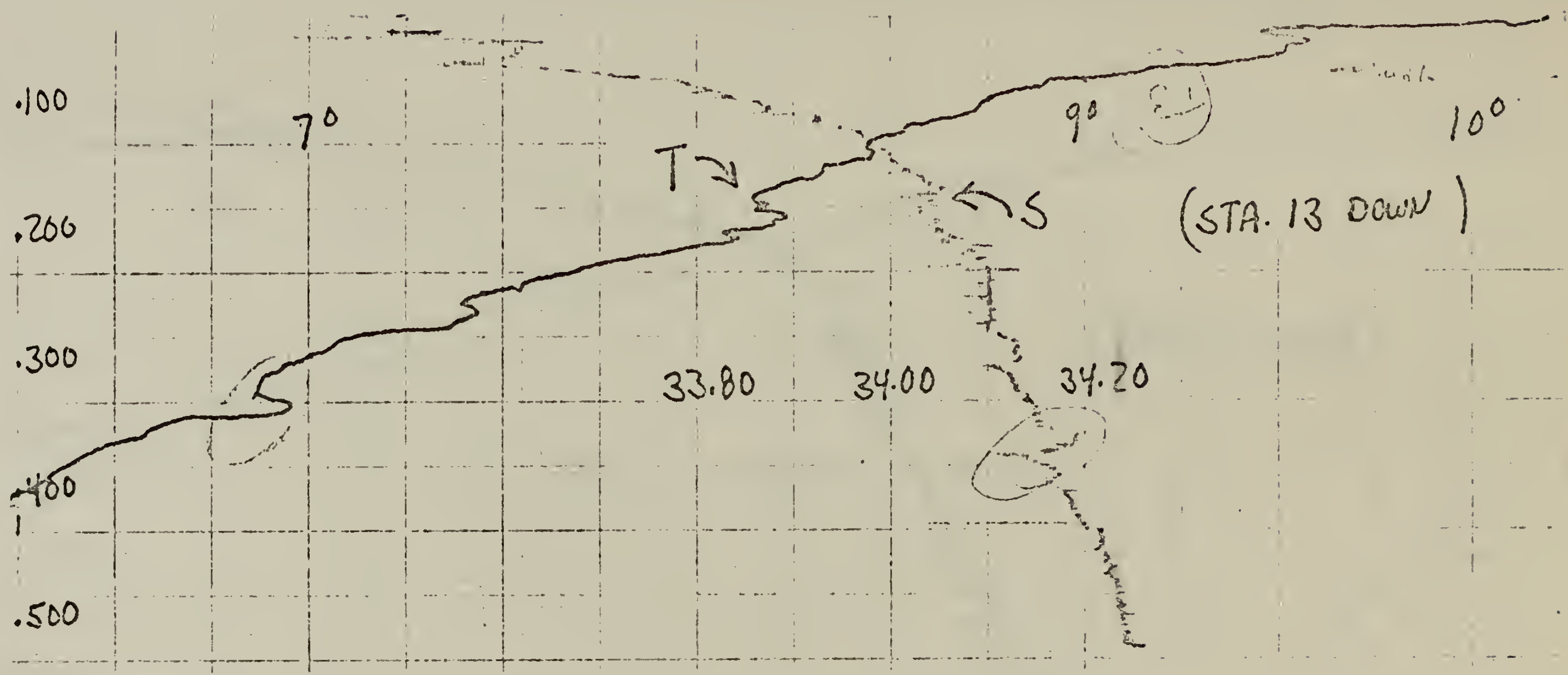

Figure 33. SV/STD record from section 1.

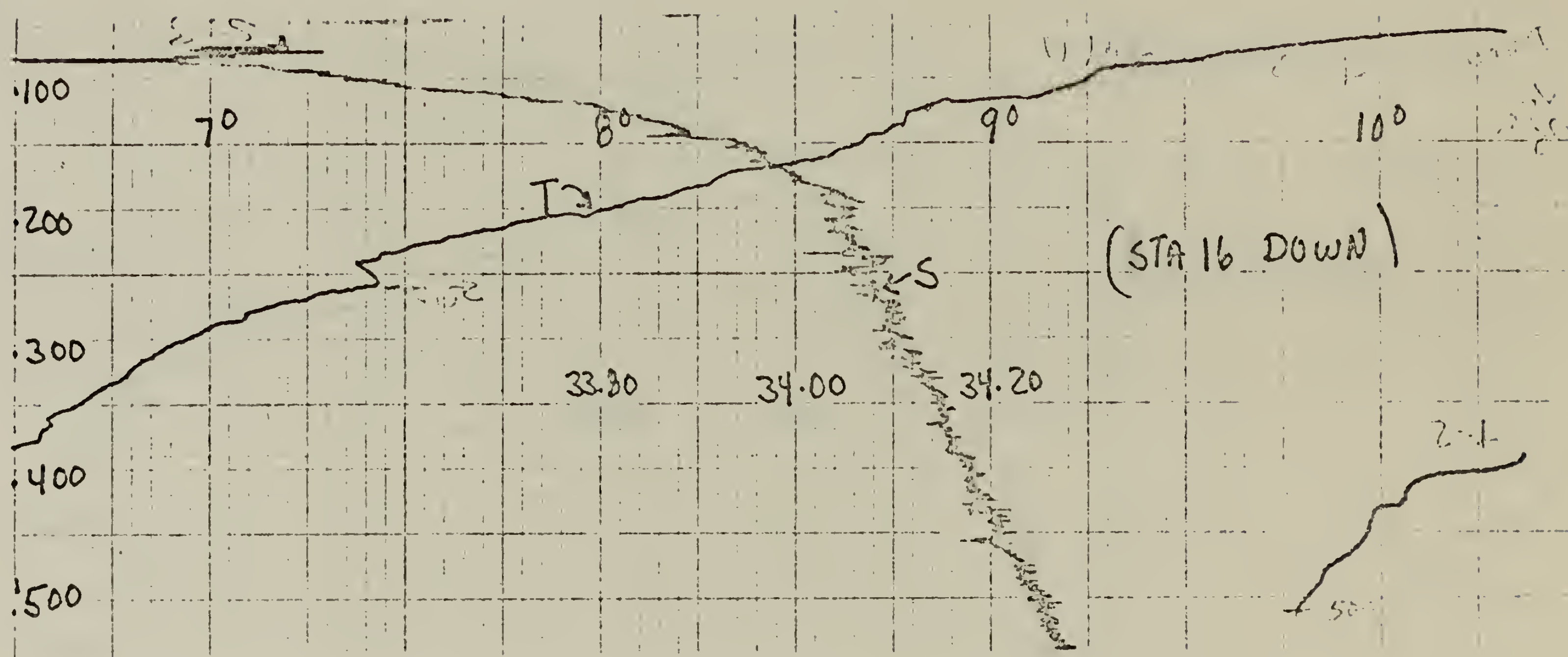

Figure 34. SV/STD record from section 2.

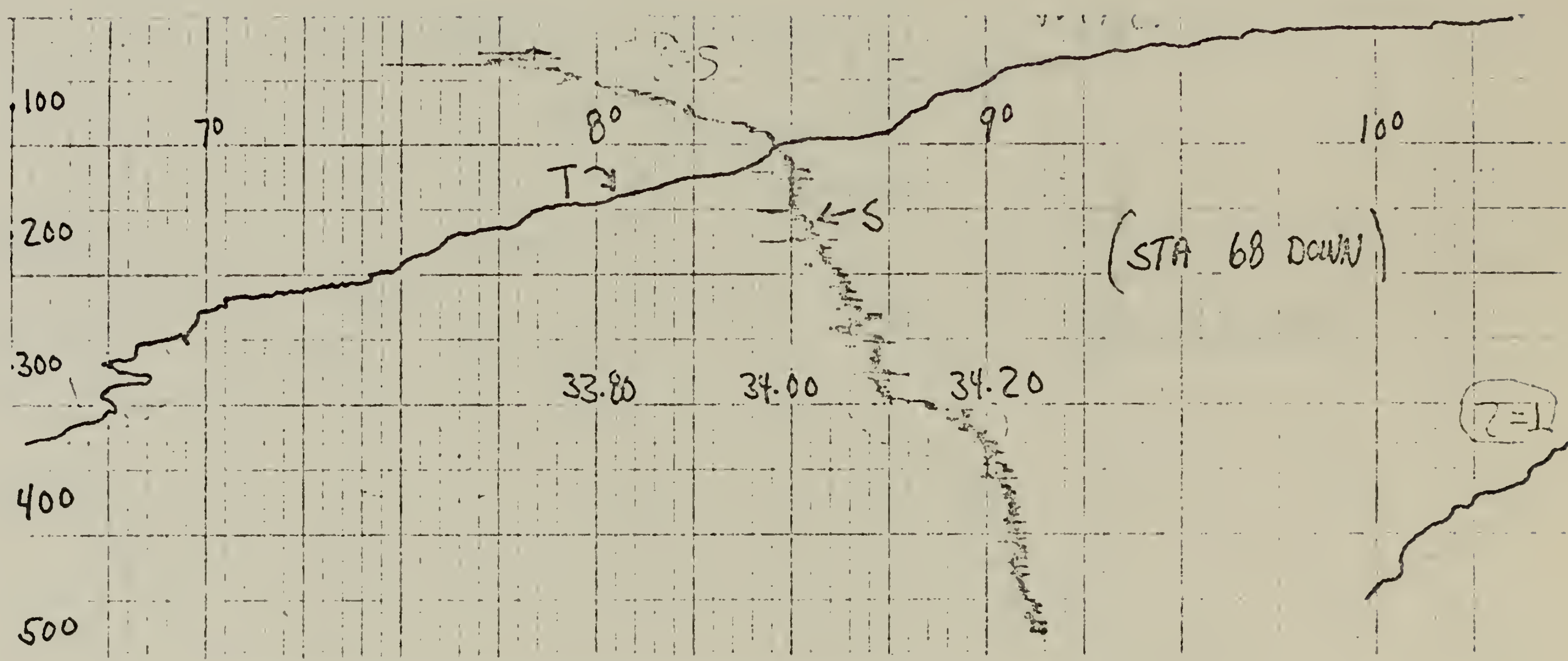

Figure 35. SV/STD record from section 3.

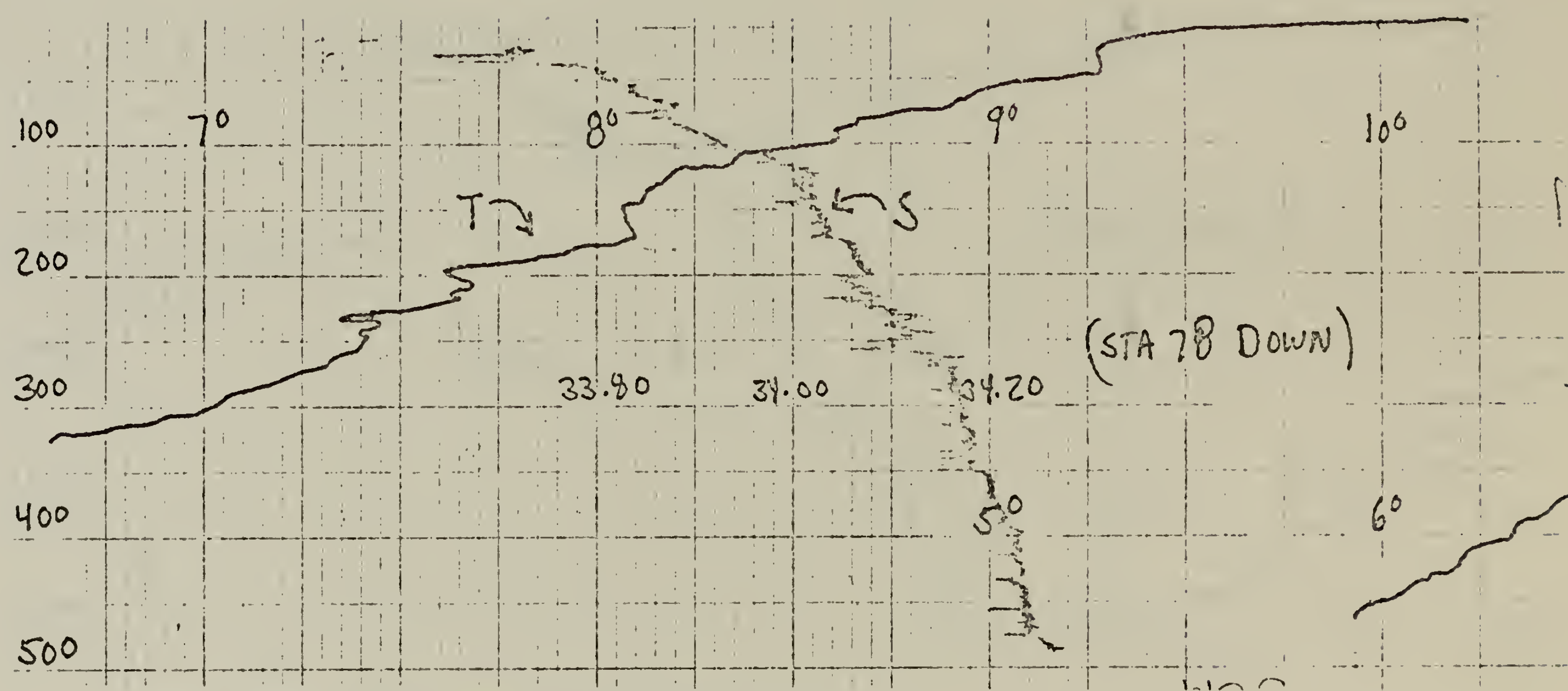

Figure 36. SV/STD record from section 4.

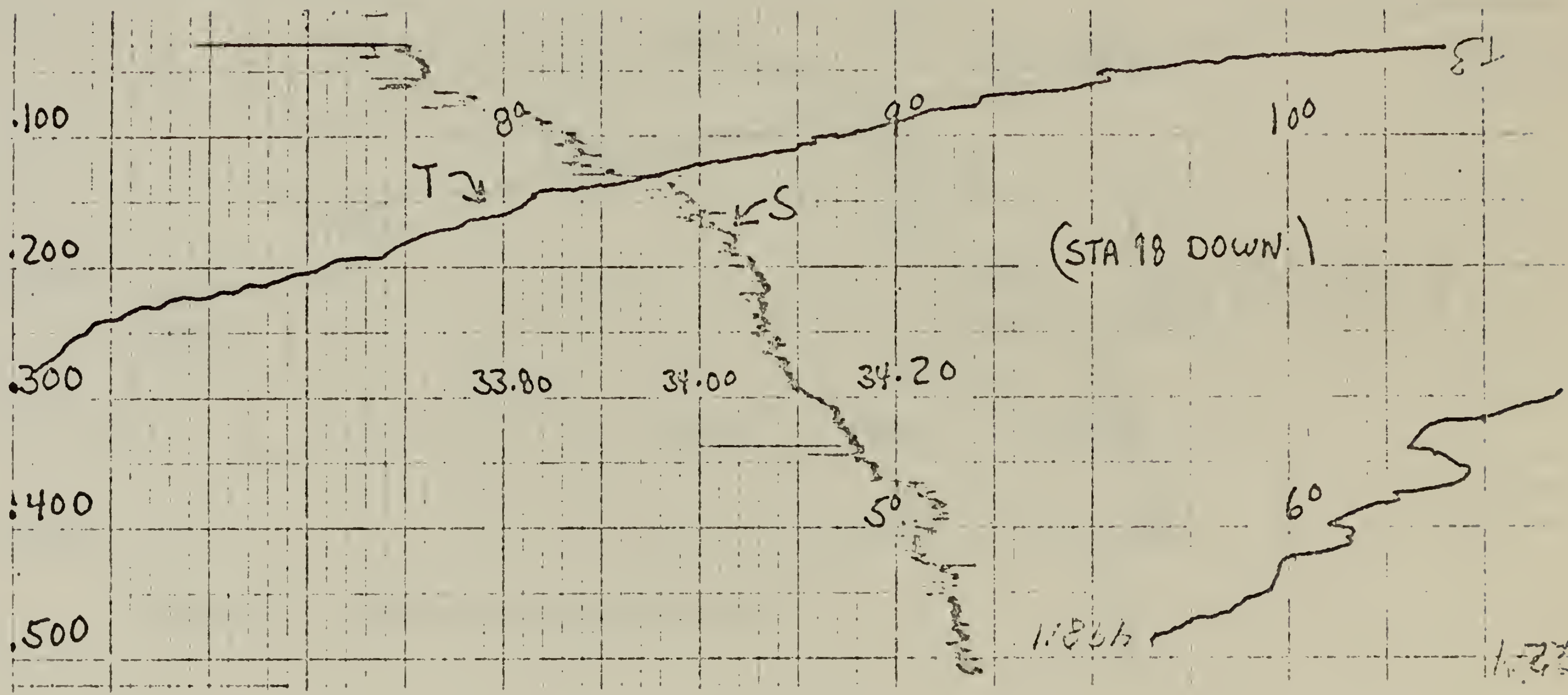

Figure 37. SV/STD record from section 5.

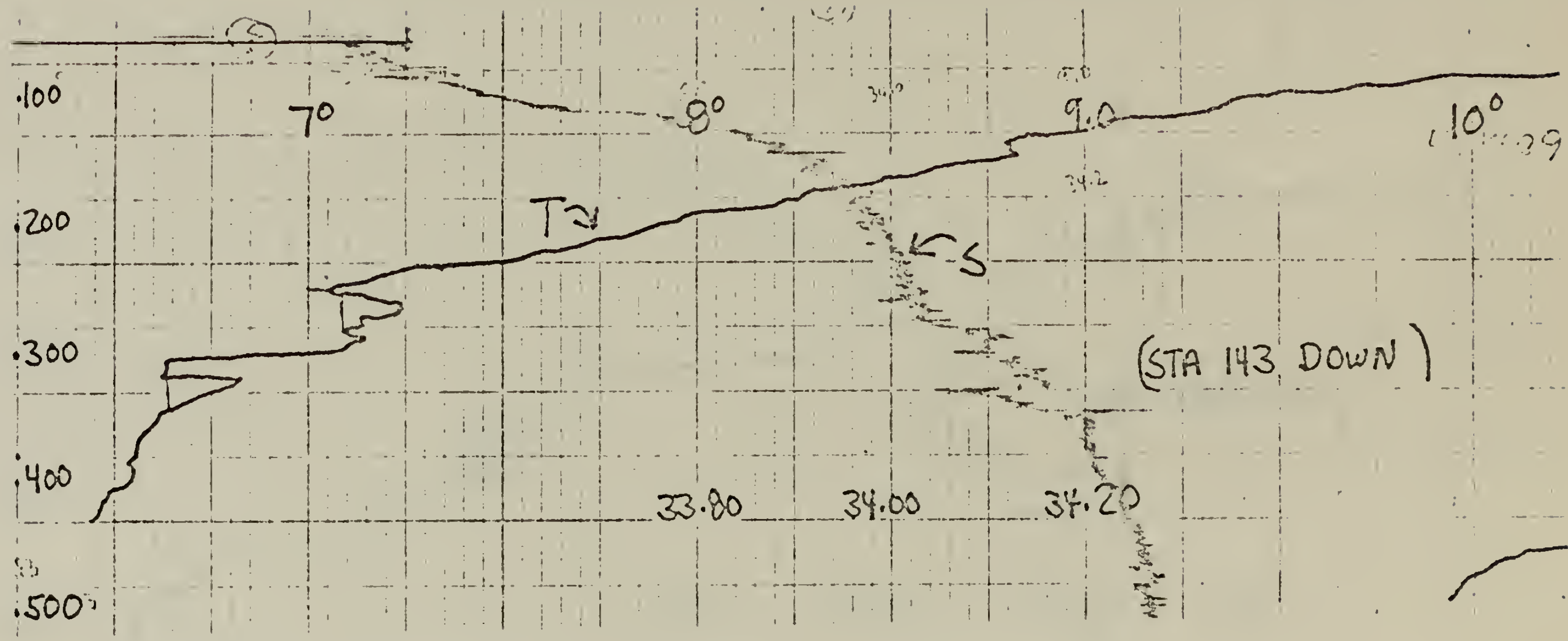

Figure 38. SV/STD record from section 6.

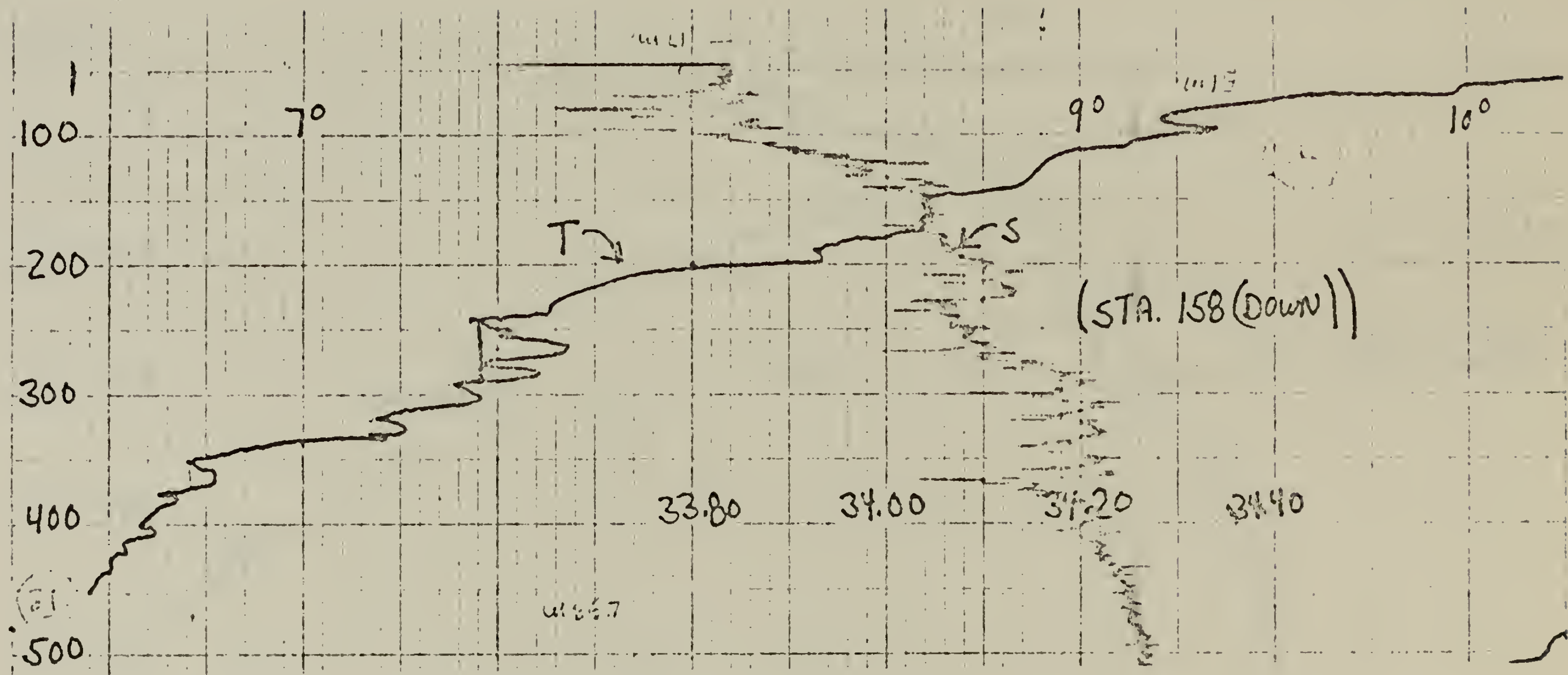

Figure 39. SV/STD chart from section 7.

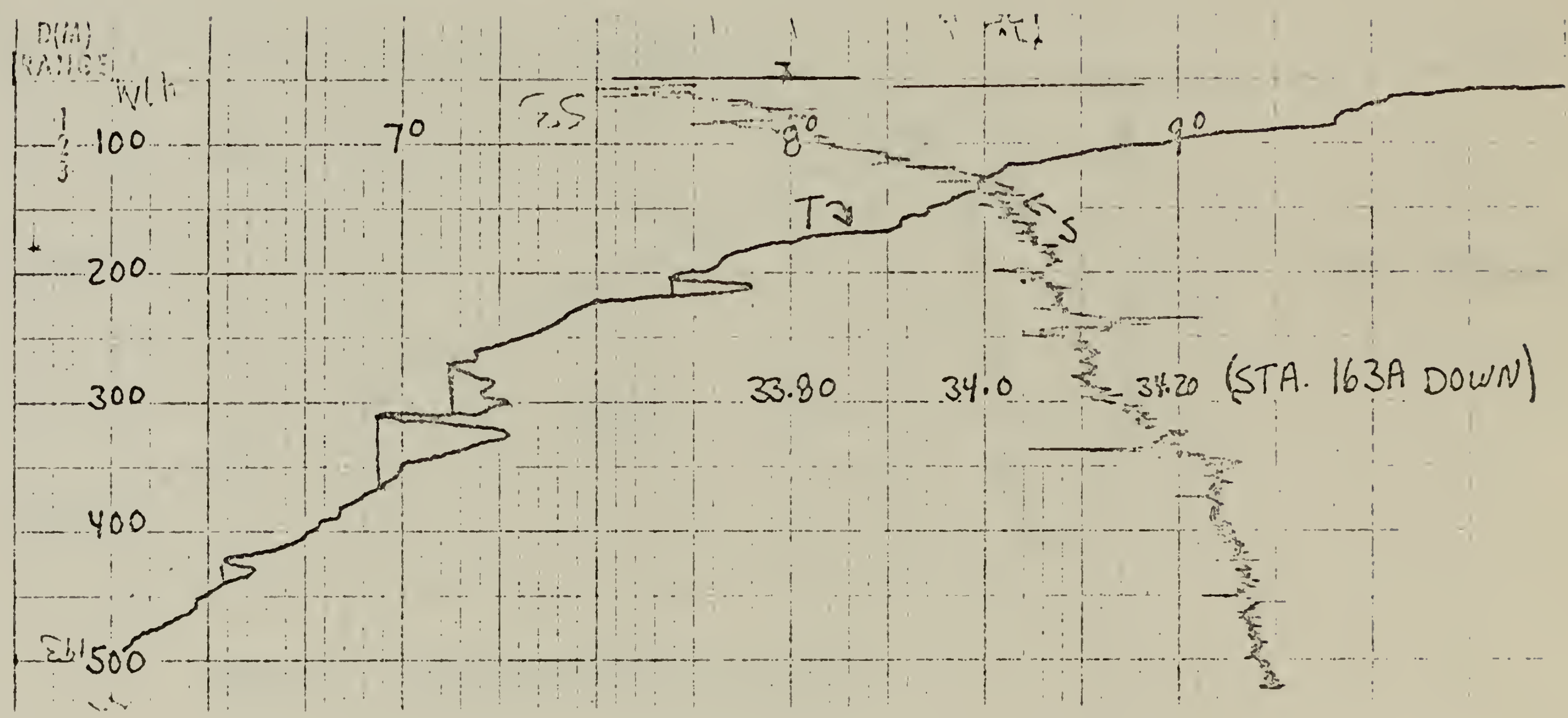

Figure 40. SV/STD record from section 8.

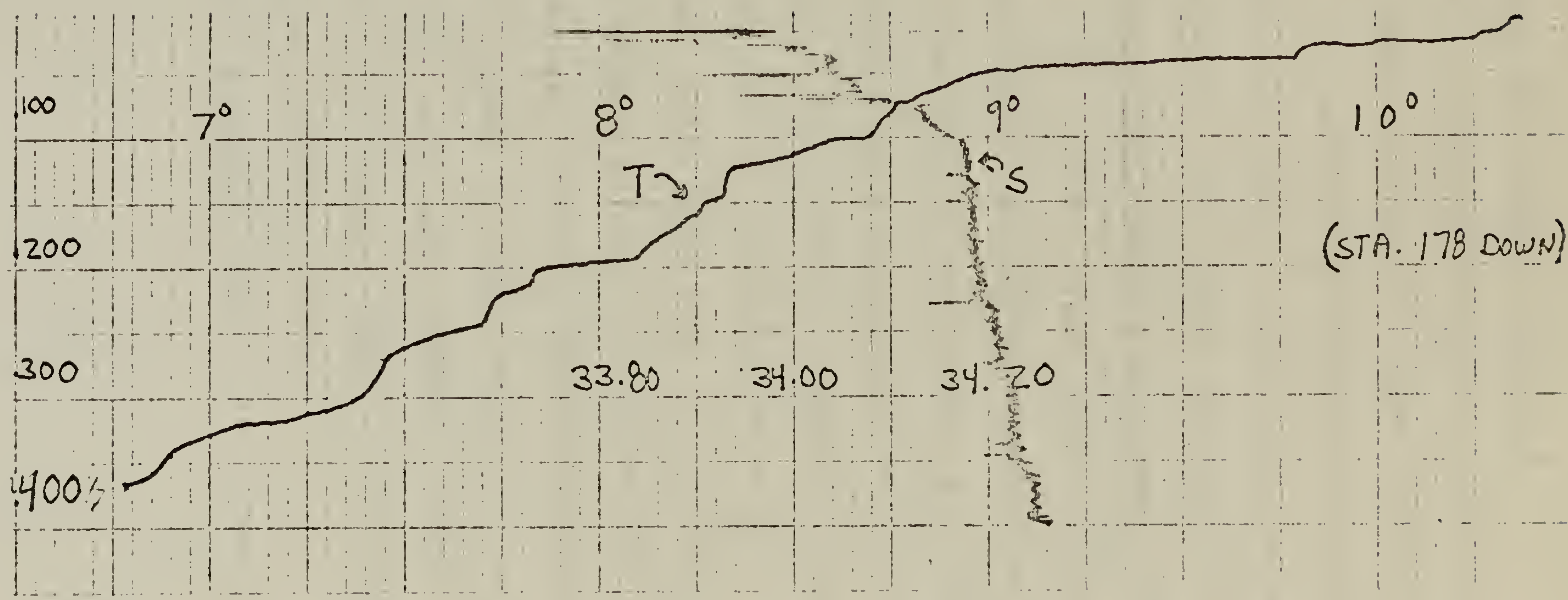

Figure 41. SV/STD record from section 9.

C. T-S PAIRS FOR SELECTED STATIONS

T-S pairs below 200 meters for selected stations along the first eight sections are shown in Figures 42-49. The T-S pairs for section nine (Figure 50) are shown from depths greater than 150 meters. Those stations nearest the coast are indicated by a "+", those stations at mid-section are indicated by a "□", and the outermost stations are indicated by a "△". For section eight (Figure 49) those stations nearest the channel islands are indicated by a "+", while the middle stations of the section and the stations furthest from the channel islands are indicated by "□" and "△" respectively. The stations closest to the coast for section nine (Figure 50) are indicated by a "△".

Of note, is the fact that on all sections for which inner, outer, and middle stations are shown, the water in the middle seems to separate water of similar types at the extreme ends. The drastic change in shape of the T-S envelopes across sections seven and eight (Figures 48-49) appear to be correlated with the abrupt change in the depths of isopleths shown earlier (Figures 27-30).

Lines of constant sigma-t are shown on each T-S plot.

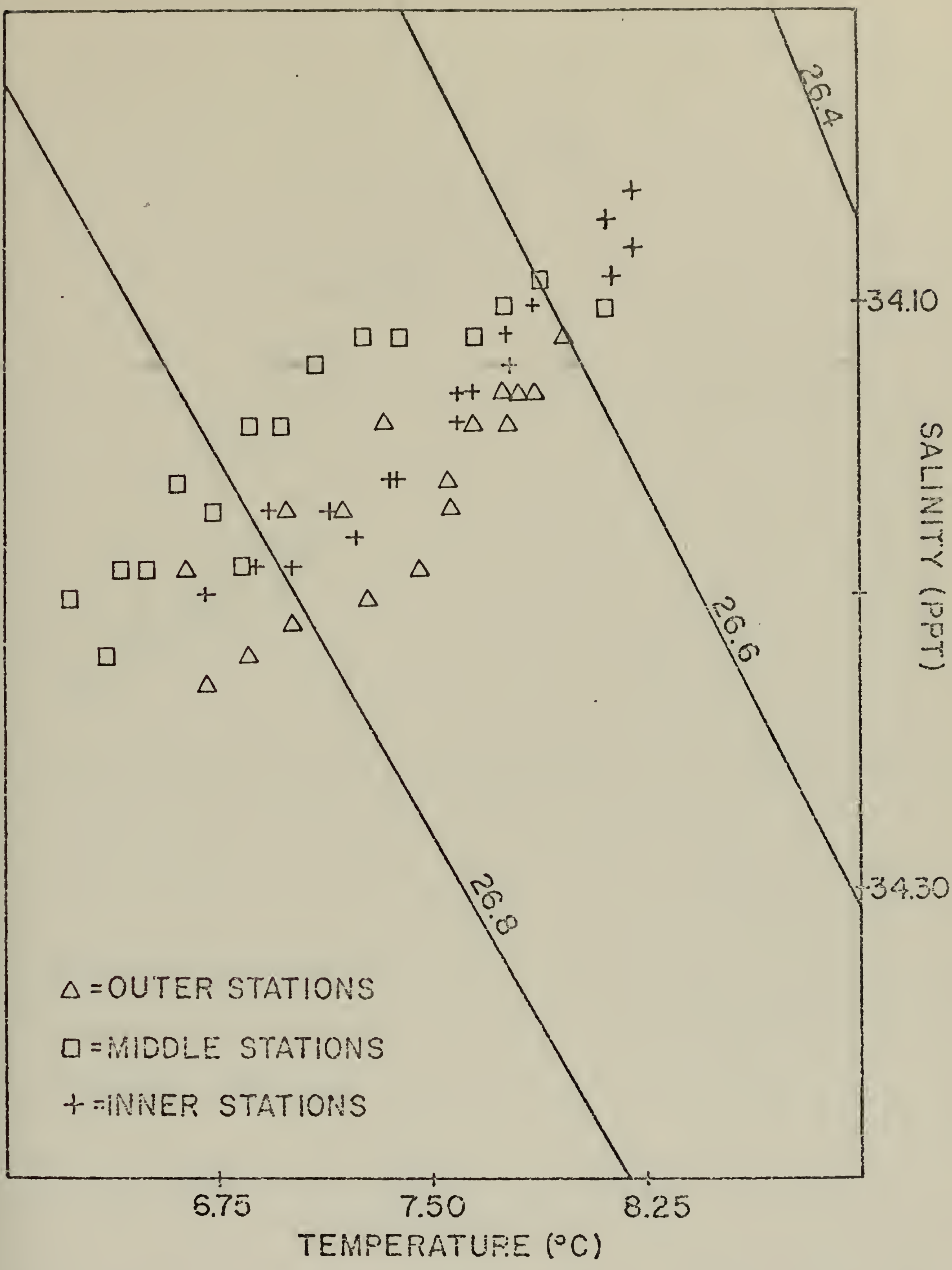

Figure 42. Selected T-S relations, section 1.

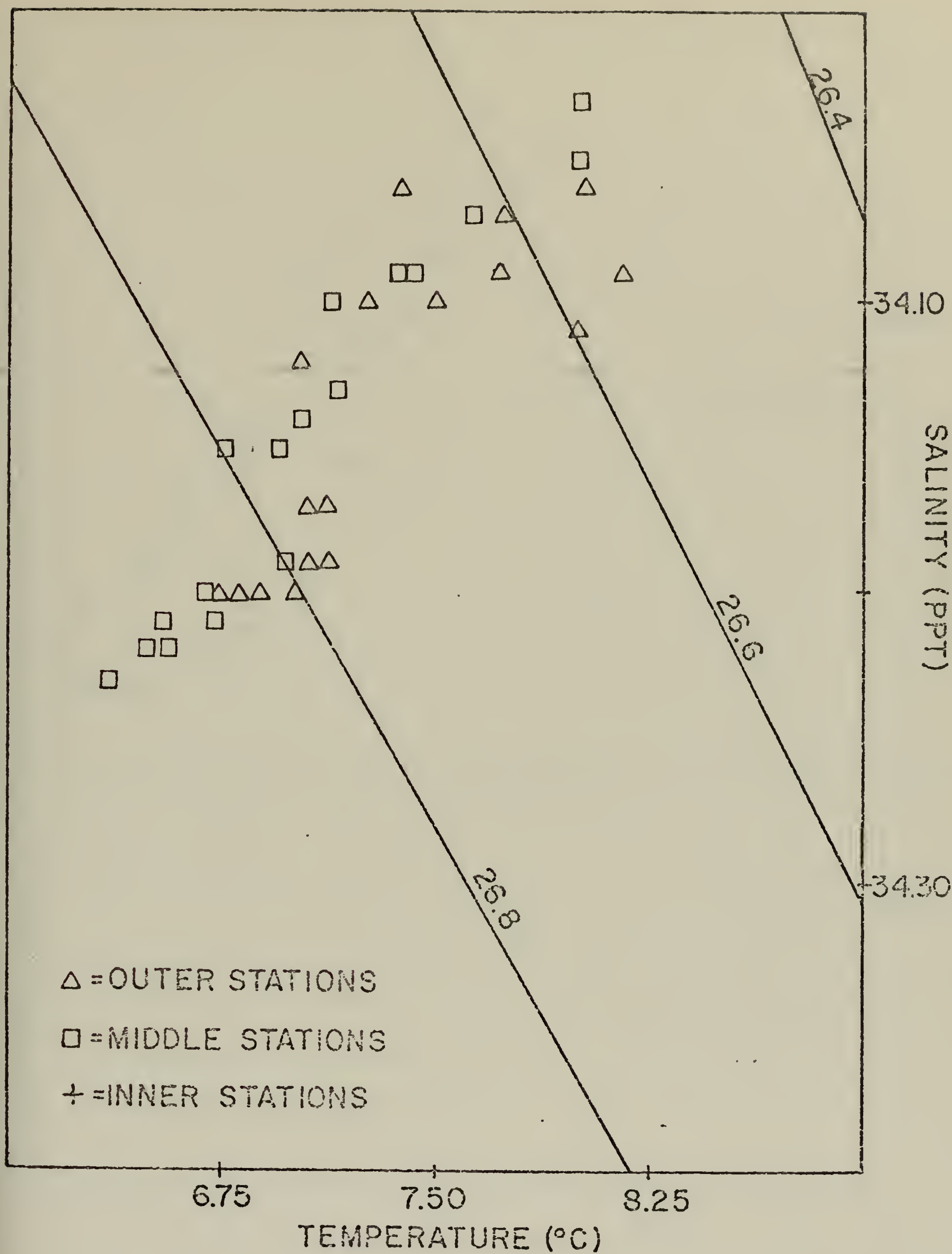

Figure 43. Selected T-S relations, section 2.

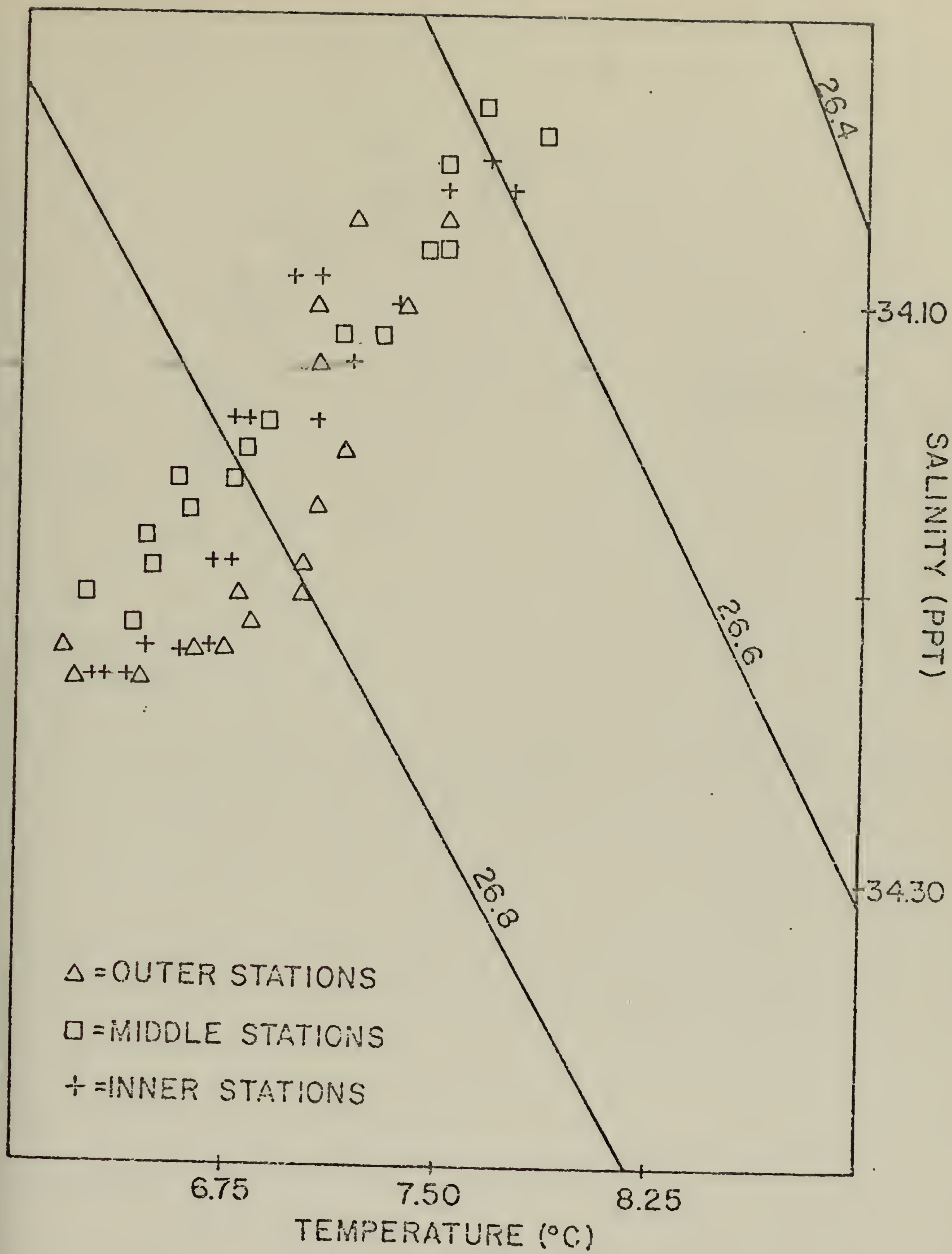

Figure 44. Selected T-S relations, section 3.

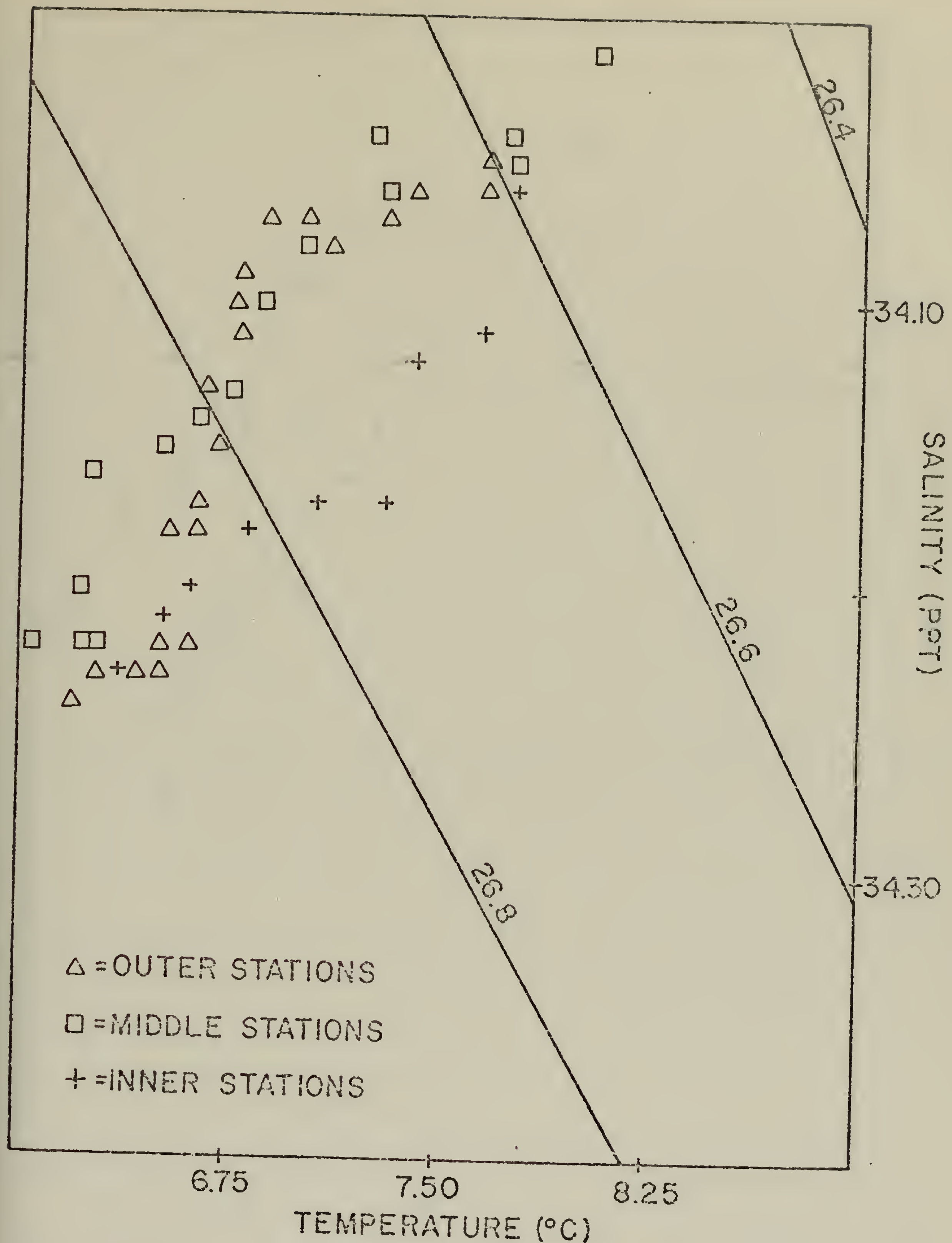

Figure 45. Selected T-S relations, section 4.

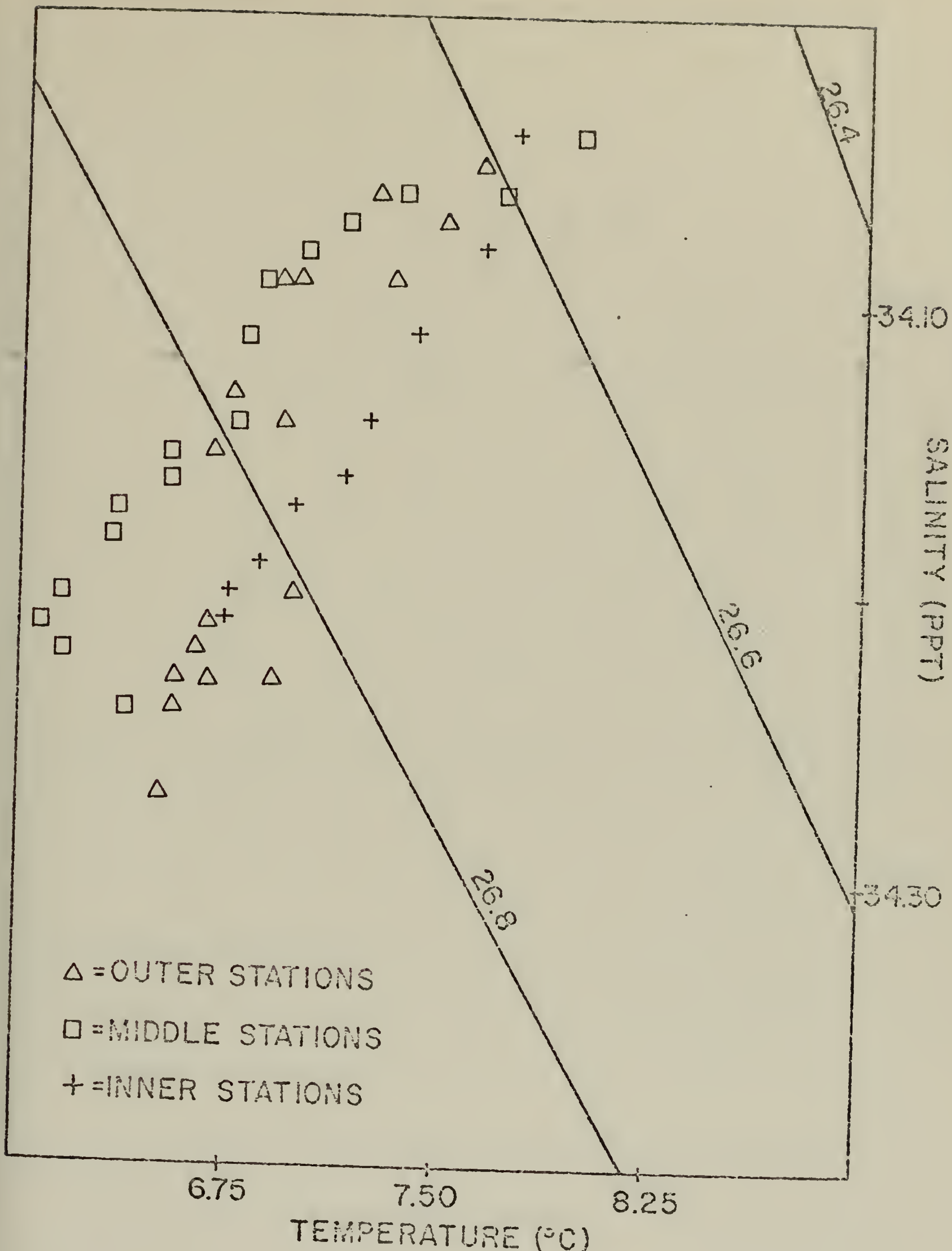

Figure 46. Selected T-S relations, section 5.

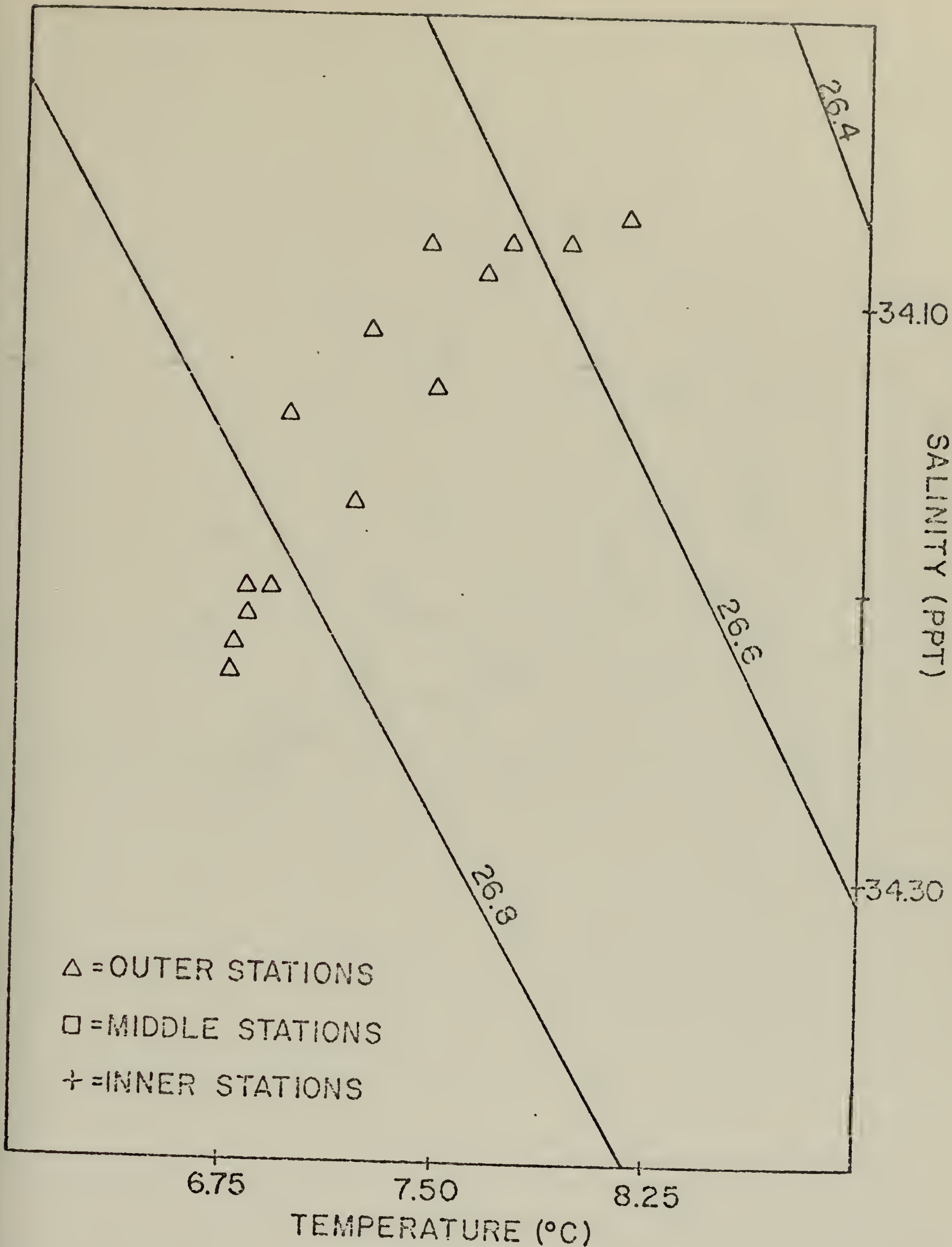

Figure 47. Selected T-S relations, section 6.

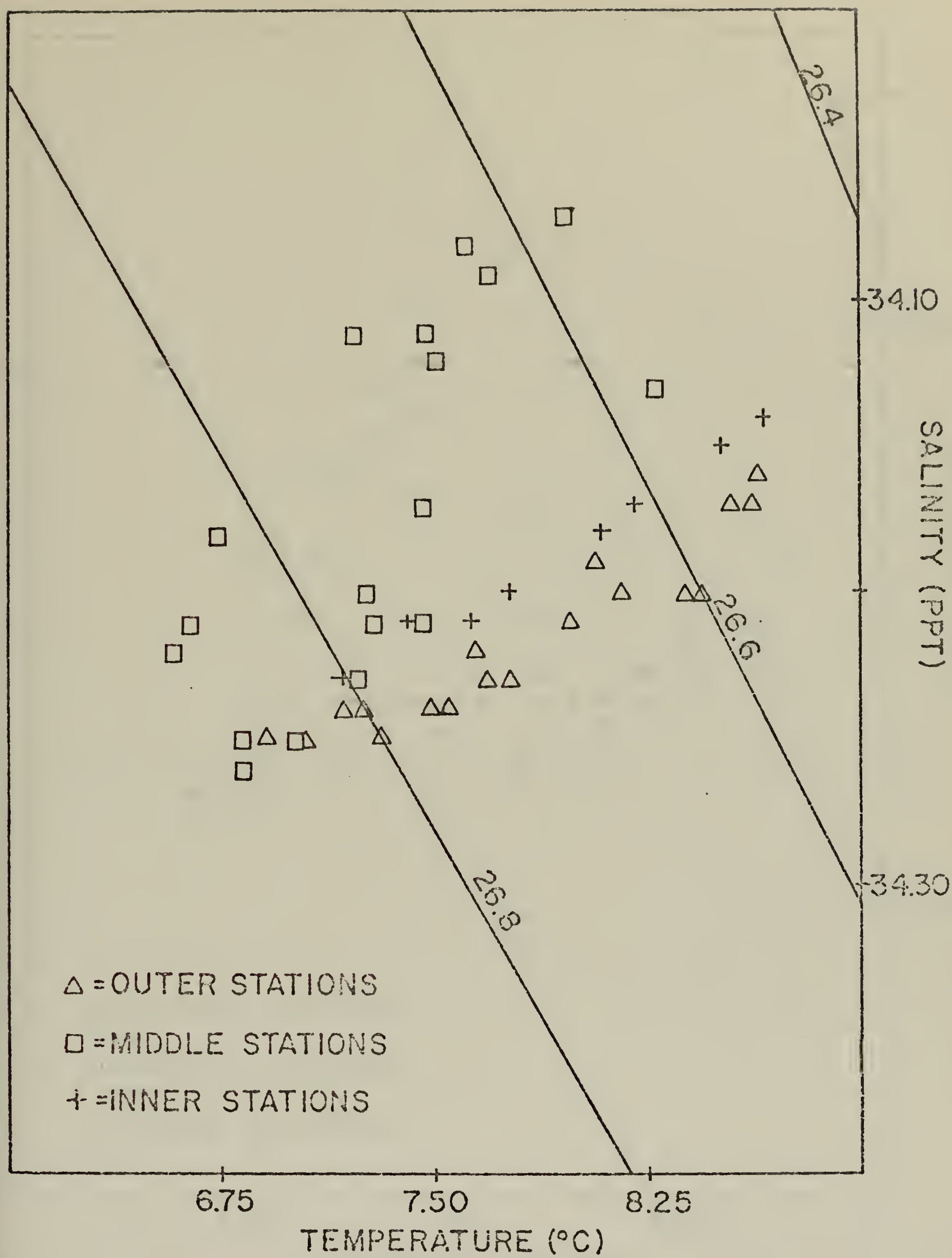

Figure 48. Selected T-S relations, section 7.

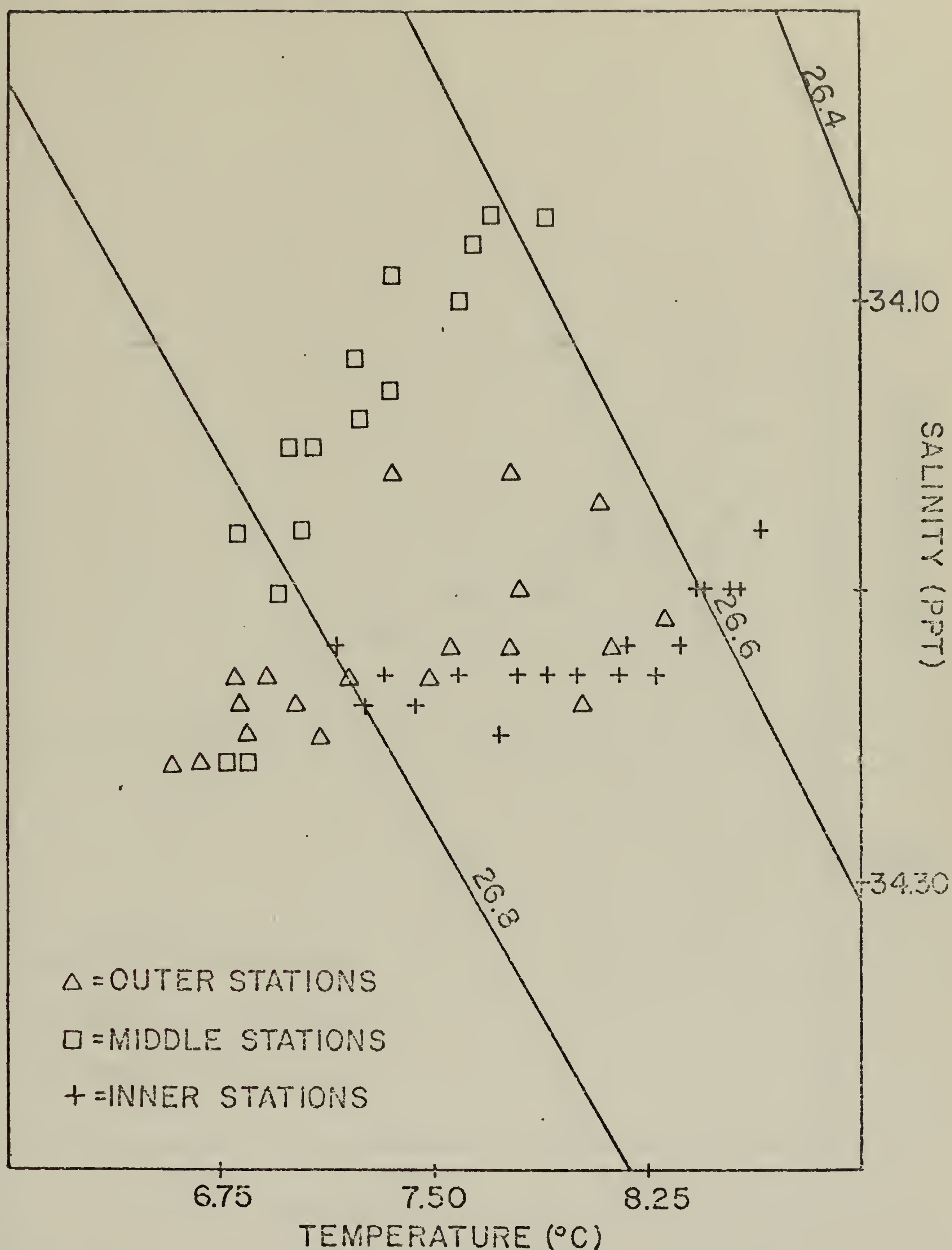

Figure 49. Selected T-S relations, section 8.

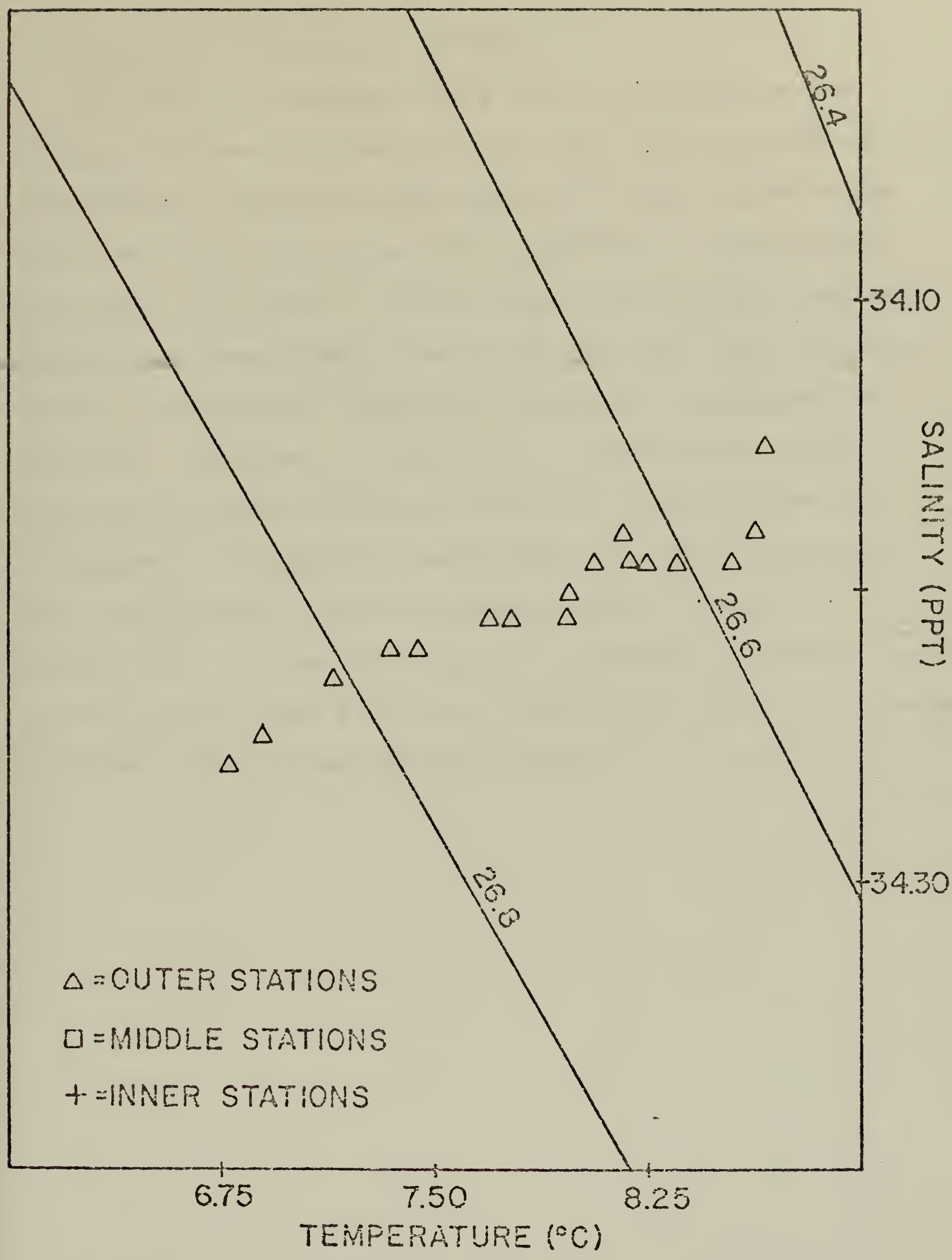

Figure 50. Selected T-S relations, section 9.

D. CONTOURS OF SELECTED ISOTHERMS

Contours of isotherms along the area covered by the cruise are shown in Figures 51-54. The plot of isotherms at the surface (Figure 51) show generally colder water nearer the coast, with isothermal lines appearing to parallel the coastline. The data on which these isotherms are based were taken at various times of both day and night over the period of the cruise, thus inferences that can be drawn must be limited. Isotherms at depths where temperature is less affected by diurnal surface cooling and heating show the development of tongues of warm water extending northward, with particularly well-developed tongues at 200 meters (Figure 53). Arrows show possible direction of current flow at 200 and 300 meters inferred from the contours of isotherms (Sverdrup, Johnson and Fleming, 1942).

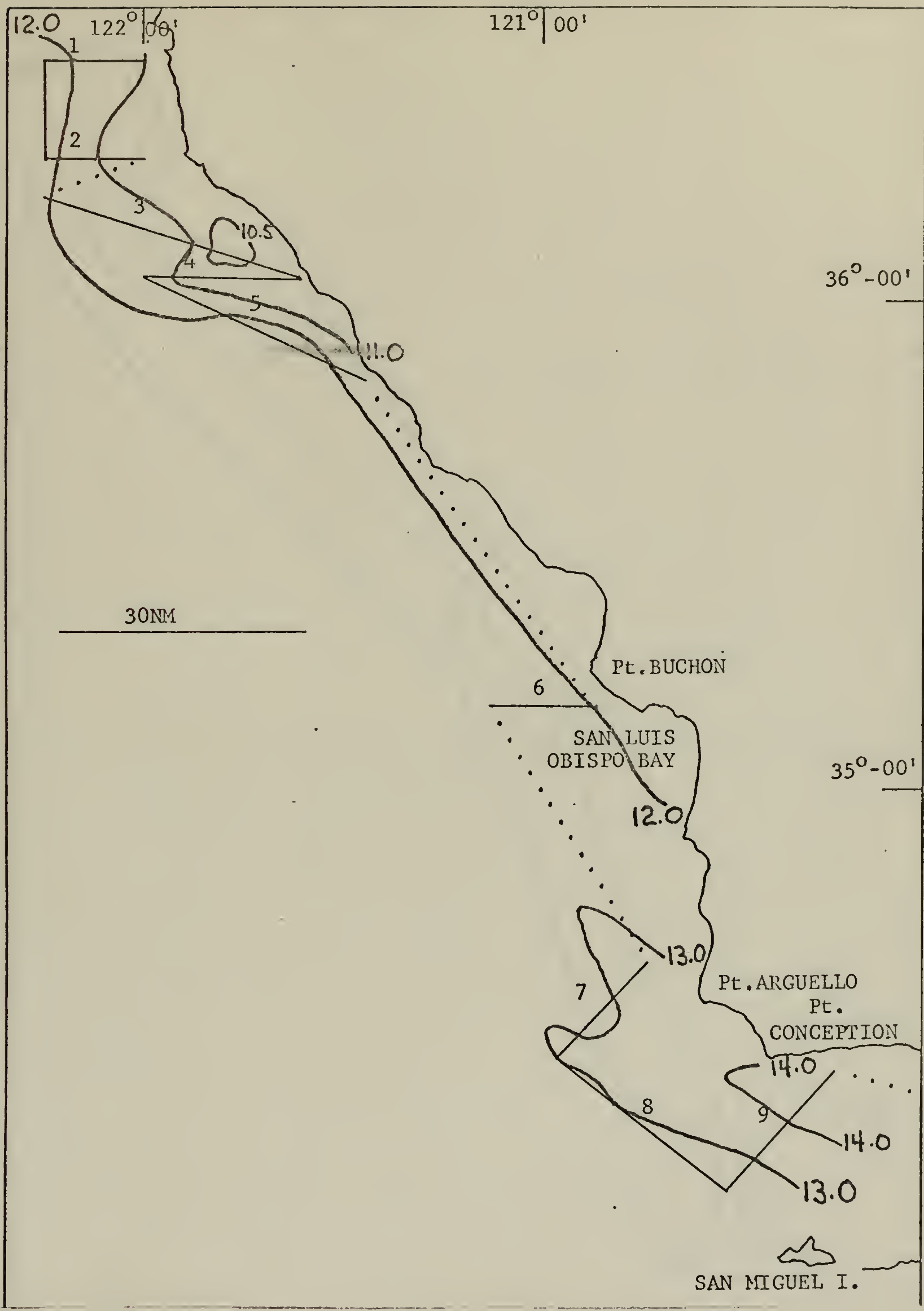

Figure 51. Contours of isotherms at the surface.

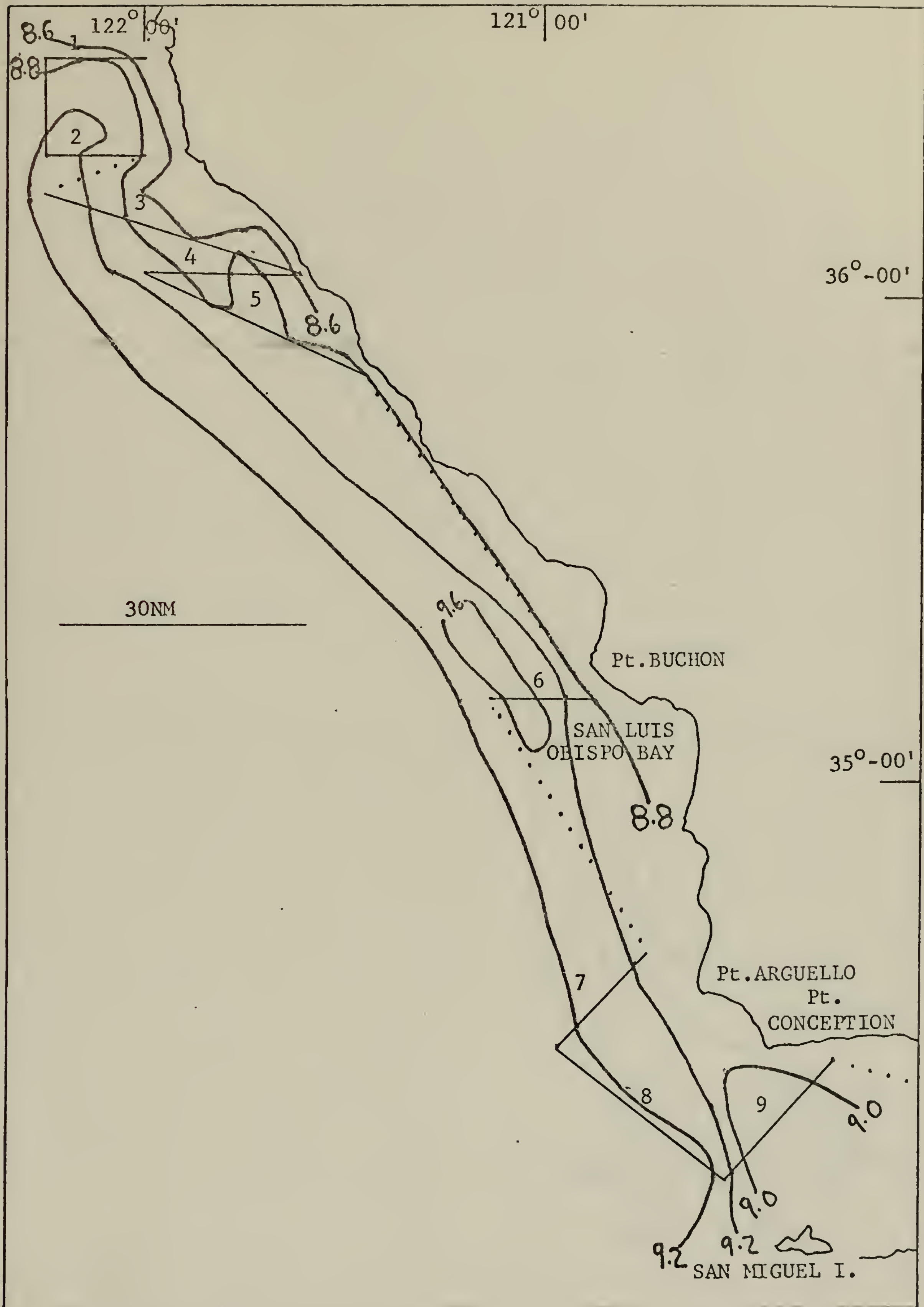

Figure 52. Contours of isotherms at 100 meters.

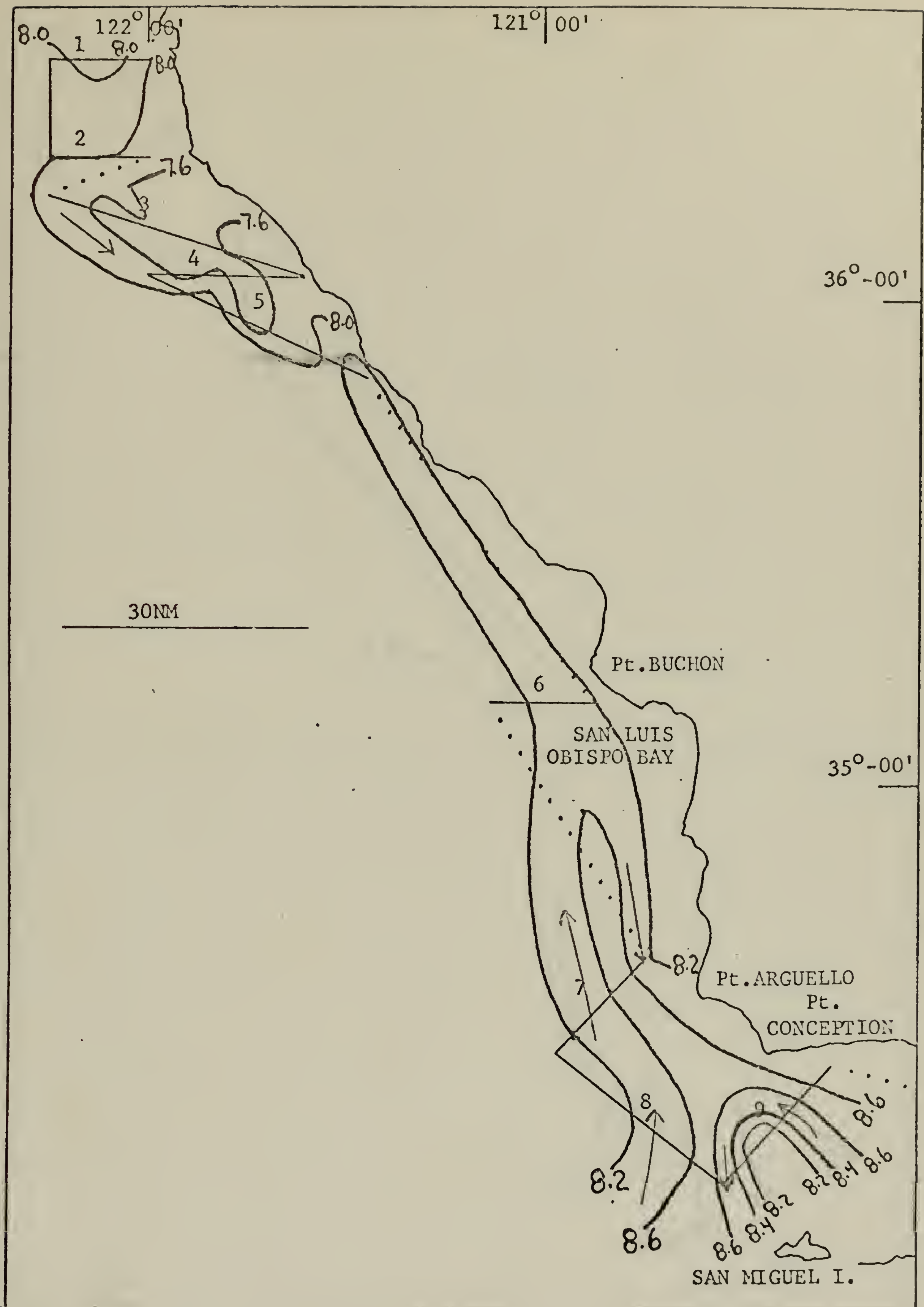

Figure 53. Contours of isotherms at 200 meters.

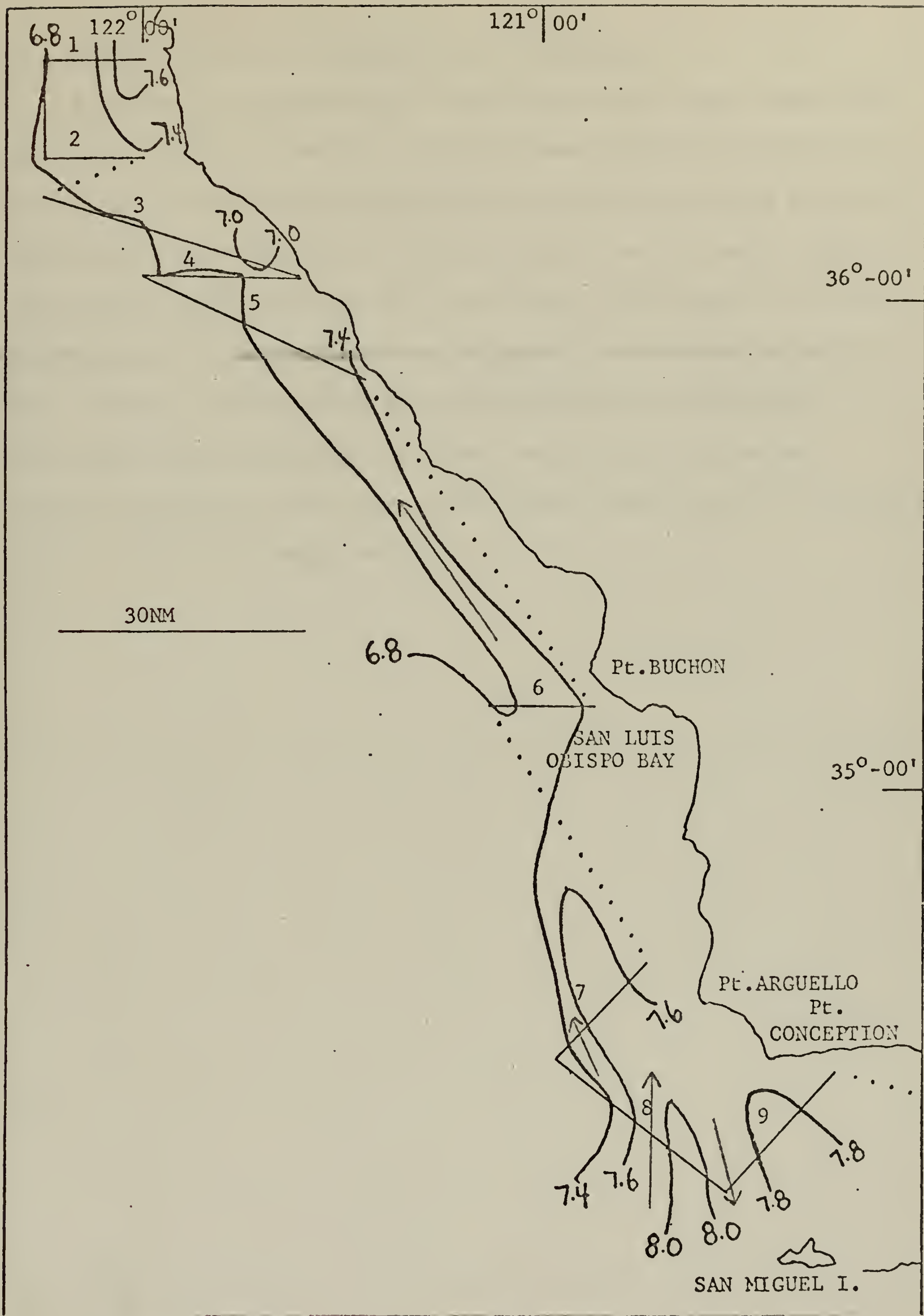

Figure 54. Contours of isotherms at 300 meters.

E. DISTRIBUTION OF TEMPERATURE INVERSIONS

A number of temperature inversions were noted along all sections. Since previous research has indicated that temperature inversions are significant in interpreting physical processes, an analysis of the distribution of temperature inversions greater than .10°C and below 200 meters is shown in Figure 55. Stations where multiple inversions occurred are circled. Of note is the concentration of multiple inversions along sections seven and eight where previous results (Figures 27-30 and 48-49) have indicated the presence of two different water masses.

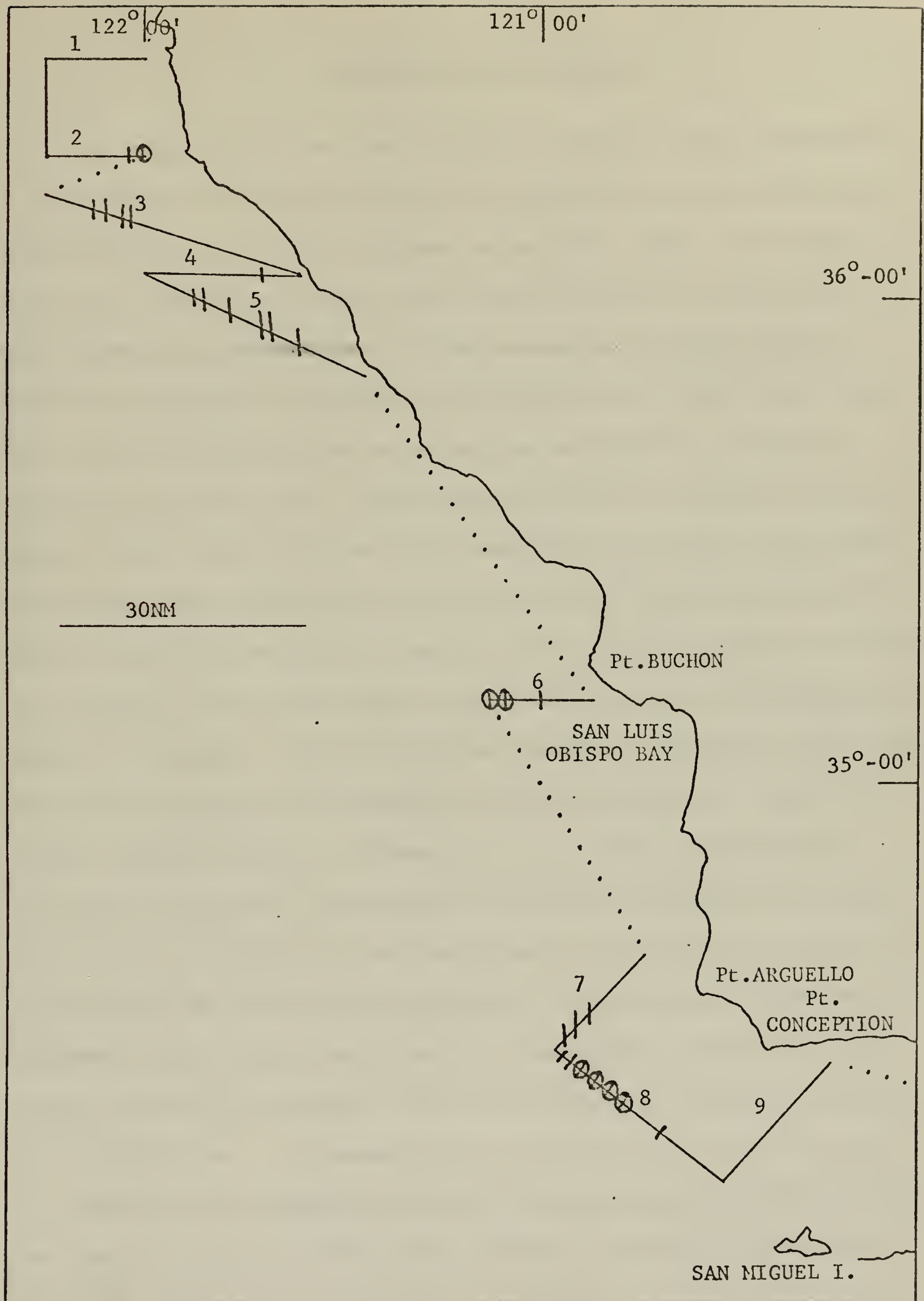

Figure 55. Distribution of temperature inversions > 0.10°C.

IV. DISCUSSION OF RESULTS

The location of several areas of interest are indicated by the vertical cross sections of temperature and salinity, particularly those in sections seven and eight. The T-S plots for these sections also clearly show the existence of two different water types. The so-called middle stations show the general T-S shape of sections 1-6, while the inner and outer stations have an envelope extremely similar to that of section nine. The inner and outer stations of sections seven and eight and the stations of section nine have T-S plots which indicate the presence of over 50% southern water below 200 meters. The T-S plots of the middle stations of sections seven and eight indicate less than 50% southern water is present. The T-S plots generally indicate that the largest percentage of southern water is found at those stations furthest from or closest to the coast with the percentage increasing with depth and decreasing with latitude. A notable exception is section four at which were found T-S pairs with as little as ten percent southern water which is somewhat less than that found at comparable points at the three northern sections. Up to 50% southern water is found at all sections. It should also be noted that if 33.9 ppt is taken as the minimum salinity at which any southern water is found (Figure 2), then the vertical cross sections of salinity show that the upper 100 meters is essentially pure northern water at all sections except seven, eight, and nine.

The SV/STD traces that are shown here (Figures 33-41) are fairly representative of those taken throughout the cruise. The existence of temperature inversions was common with at least 75 being found ranging in depth from 90 meters to 450 meters, in intensity from .03° to .32°C, and in thickness up to 50 meters. Generally speaking, the intensity, thickness, and depth were all greater at the southern stations. The occurrence of multiple inversions at stations 161-164 is notable because other results point to this area as being a possible boundary between two distinct waters. The characteristic shape of the salinity trace is interesting showing a rapid increase the first 100 meters with a very slow rate of increase thereafter.

A further interesting fact is that large wire angles (up to 35°) were frequently observed to occur as the SV/STD was being lowered through an area of temperature inversion. Lovett [1968] has also observed this fact and has stated that the cause is current shear. This could imply that a cause of the temperature inversion is a jet or sheet of warm water intruding into an area at a high velocity. It would be of interest to map the horizontal extent of the inversions while simultaneously measuring the vertical current profile.

Sverdrup et al [1942] has indicated that the direction of current flow may be inferred from the existence of horizontal tongues of temperature. When facing downstream, the

colder temperatures are on the left. It can then be seen (Figures 53-54) that there may exist both northward and southward flowing undercurrents at 200 and 300 meters. Further, the variation of T-S relationships across a section as mentioned earlier indicates that there is somewhat different water in the middle of a section than at the ends. It is not felt that any of these results indicate firmly that the boundaries of the undercurrent were defined by this cruise other than that there is an outer boundary further from the coast than any of the stations occupied. Of course, the precise definition of a geophysical boundary is difficult to obtain. Many processes are operating simultaneously, and the medium is often in turbulent motion. Although the data obtained do not exactly locate the boundaries, they are important because the sampling density is greater than most previous cruises in this area. However, sampling limitations still exist and hamper data interpretation.

V. CONCLUSIONS

The California undercurrent, as defined by its characteristic distribution of temperature and salinity, is present below 200 meters as far north as 36° - 31.1' latitude during the period of this investigation. It is likely present in filaments separated by a southward flowing current. Figure 56 shows a <u>suggested</u> pattern of flow between 200-300 meters. Clearly, additional data are required to be more specific about this area. Specifically, future investigations on the Wickham and Bourke proposal 1972 should be conducted off Pt. Arguello in an effort to determine the nature of the transition areas implied in this thesis to exist around stations 155-170.

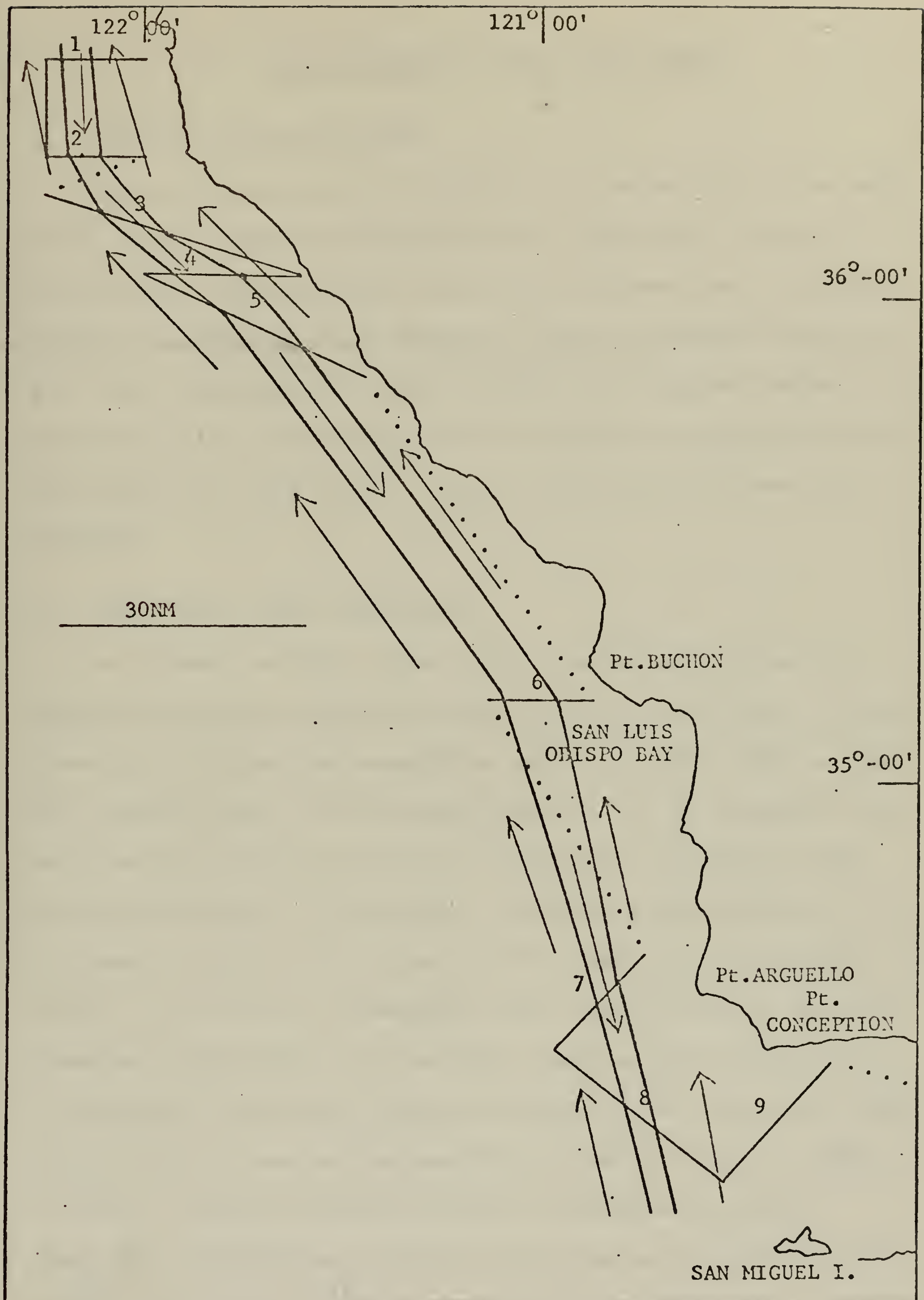

Figure 56. Suggested boundaries of California undercurrent.

VI. RECOMMENDATIONS FOR FUTURE WORK

A. WORK ON AVAILABLE DATA

The processing of the digital data obtained in the BARTLETT cruise should be completed (see Appendix). Some geostrophic calculations should be performed and the distribution of salinity on a constant sigma-t surface should be plotted. The results would possibly be of great value in supporting the conclusions of this paper and aiding the investigation in fisheries, coastal upwelling and nearshore dynamics.

B. ADDITIONAL DATA COLLECTION

As already stated, this report indicates at least one geographical area which deserves further attention. A very fine grid of stations should be set up in this area to take STD readings and current measurements. It is expected that more accurate boundaries of the different waters in this area could then be determined. Further cruises should be planned to define the nature of the undercurrent further off shore. It is also recommended that future cruises utilize chemical techniques and equipment such as the autoanalyser to determine chemical characteristics of the water and their distribution along and across the probable areas of undercurrent. Gaylord Paulson, Naval Postgraduate School, Monterey, California, is currently working with the Technicon® Autoanalyser® in Monterey Bay. His work, showing

the use of this instrument in obtaining continuous in-situ measurements of the distribution of nutrients, is anticipated to be published in late 1972.

APPENDIX A

The processing of the data obtained on this cruise was complicated by several factors. Perhaps the most overriding was that the digital data were in the form of punched paper tape and could not be put into a useful format in the time available to prepare this thesis. A combination of two factors made processing of the analog data difficult. One was an equipment malfunction which caused the chart drive to be inoperative during the first 15 to 25 meters of each downcast and the last 15 to 25 meters of each upcast. The second was a failure to recognize that this was occurring so that the chart could be properly set with the pens at twenty or so meters and then annotated with correct depths from the digital display. This problem was recognized only after several stations, and subsequent charts were correctly annotated. To find depth corrections for those early charts, the following method was used. The length (i.e. depth) of the up trace was found by direct measurement. A nominal value of 20 meters was added to find total actual depth. This value was compared to the maximum depth reached by the temperature down trace. The difference was applied as a constant correction. In order to ensure that whatever error existed in this method would be constant for all stations (thus having accurate relative values), the method was applied even to those stations where correct depths were annotated

on the chart. It was found that the average error in absolute depth was less than five meters.

Processing of the punched paper tape proved to be extremely difficult. First the tape (some 25 rolls) had to be rewound. Then it had to be run through an optical scanner and read on to 7-track magnetic tape (a set of 12 tapes had to be run through twice when a check of the first run indicated that nothing had been read on the 7-track tape).[1] Following generation of the 7-track tape, the information must then be put on 9-track tape, where the task was to substitute numbers for letters (letters are printed when punched tape fails to contain a carriage shift signal), trim groups of 9 digits into meaningful values for temperature, salinity, and depth, and finally group these values according to stations. Working with digital and analog data concurrently, the author had reached the stage of having the information put on the 9-track tape when he realized that he only had time to concentrate solely on the analog data.

In the absence of digital data, values of sigma-t were not calculated and the valuable tool of plotting temperature and salinity contours on surfaces of constant sigma-t was not available. However, the information is available on the 9-track tape, and a minimum amount of additional processing would produce data in a form that would be extremely valuable in analyzing the extent of the California undercurrent.

---

[1] One cannot feel that he has experienced true despair until he has stood in the midst of a pile of paper tape with pieces wrapped around his arms and head gazing at impossible combinations of twisting and spiralling.

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ABSTRACT

Continuous temperature and salinity profiles were made on nine sections of stations between Monterey and Santa Barbara to locate the California undercurrent. Temperature-salinity relations across all sections indicated the presence of southern water characteristic of the undercurrent. Tongues of high temperature water were found to extend northward implying northward and southward flow both at 200 and 300 meters. The sudden fall of isotherms coupled with a rise in isohalines across sections seven and eight together with the observation of numerous temperature inversions indicated the influx of warm, salty water from the south.

These data suggest that the boundaries of the California undercurrent between Monterey and Santa Barbara extend from five nautical miles to beyond 25 nautical miles offshore below 200 meters during the period of this investigation.

KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
California current system						
California countercurrent						
California undercurrent						
Coastal currents						
Davidson current						
Salinity-temperature variations						
Southern water						

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